'Multi-cropping', intercropping and adaptation to variable environments in Indus South Asia

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Abstract

Both today and in the past human populations manage crops in a range of different ways. A variety of methods can be used singly or in conjunction to reconstruct these choices, and the investigation of cropping strategies lends itself to the exploration of a range of socio-economic and political themes. This paper explores the nature of cropping strategies, and endeavours to 'unpack' the concept of 'multi-cropping' by considering the diversity and variation in the cropping practices utilised by the populations of South Asia's Indus Civilisation. It argues that nuanced interpretations of the evidence provided by the combinations of crop seeds and weeds present in specific context and phases of occupation have the potential to reveal much about Indus cropping strategies, which in turn enable consideration of issues related to adaptation, intensification and resilience in the face of changing social, political, economic and environmental climates.

Keywords

Cropping strategies, 'multi-cropping', environmental diversity, adaptation, resilience, Indus Civilisation, South Asia

I. Introduction

There is a growing body of literature devoted to the investigation of how human populations manage crops, with themes including the socio-economics of intensification, extensification, diversification, water supply, land ownership and labour organisation (e.g. Halstead 1992; Morrison 1994; Bogaard 2005; Marcus and Stannish [eds] 2006; Bogaard *et al*. 2013; Morehart and De Lucia [eds] 2015). The quotidian practices of sowing, tillage, rotation, fallow, weeding and watering provide fundamental insight into crop management, but they are challenging to resolve archaeologically. These aspects have been investigated to varying degrees of resolution in regions that receive rainfall in specific seasons: for instance in places like Europe and the ancient Near East (e.g. Jones *et al*. 1999; Bogaard *et al*. 1999, 2001, 2011, 2015; Bogaard 2005, 2015; Halstead 2014; Styring *et al*. 2016), which are dominated by winter rainfall; and in Mesoamerica (e.g. Ford and Nigh 2010), sub-Saharan Africa (e.g. Stone *et al*. 1990; Stump 2013), and parts of East Asia (e.g. Fuller and Qin 2009; Weisskopf *et al*. 2014; 2015), and south and eastern India (Morrison 1992; Kingwell-Banham *et al*. 2012; Weisskopf *et al*. 2014, 2015), which are dominated by summer rainfall. In these instances, where rainfall primarily comes in the one season, crop species suited to those water availability regimes were exploited, and farming activities were concentrated in particular times of the year. In comparison, the agricultural strategies utilised in the challenging climatic and environmental conditions that prevail in other parts of the world, where both winter and summer rainfall systems operate, have the potential to be multi-seasonal and thus more complex in terms scheduling and management, but they are less studied and thus less well understood. The South Asian subcontinent stands out as a region characterised by a number of distinctive forms of early farming including the exploitation of winter and summer cereals, pulses and fruits (Fuller 2011; Kingwell-Banham *et al*. 2015), the cultivation of which were enabled (and constrained) by the high level of environmental diversity. The populations of South Asia's Indus Civilisation made use of a range of these crops and managed to occupy and thrive in a zone that straddled an important environmental threshold where winter and summer rainfall systems overlapped (Fig.1; Petrie *et al*. 2016, in press/2017; Petrie in press/2017).

The need to unravel the complexities of Indus cropping strategies has long been highlighted as a fundamental challenge for South Asian archaeobotany (e.g. Fairservis 1967; Vishnu-Mitre and Savithri 1982; Fuller and Madella 2002; Madella and Fuller 2006; Weber *et al*. 2010).

Descriptions of Indus cropping practices have often made reference to strategies like 'mixed-cropping', 'double-cropping' and 'multi-cropping' to characterise a range of approaches to growing multiple crops in either one or more seasons (e.g. Vishnu-Mitre and Savithri 1982; Chakrabarti 1988; Butler 1999; Weber 1999, 2003; Fuller and Madella 2002; Wright 2010). Such terms have implications for understanding the intensification of crop production, the degree to which diversification was important, and the impact of those factors on the sustainability of farming practices. While cropping in more than one season has certainly been discussed, and coherent models for diversity in practices have been developed (e.g. Weber 1999, 2003), the nuances of farming as practiced by farmers on the ground has not typically been addressed. It is arguable that there has also been a tendency to apply the terms multi-cropping and intensification to archaeobotanical assemblages uncritically, and the nuances of cropping multiple species with a range of environmental requirements during one season and the rotation of these across strategies seasons has not be explored in as much detail.

South Asia's Indus Civilisation is an ideal laboratory for revisiting the way in which cropping practices and strategies are characterised, and the ways in which they can be identified archaeologically. This paper reviews the concepts that underpin our understanding of cropping strategies and explores the nature and distribution of the extant data that can be used to discuss the cropping and multi-cropping strategies used by different Indus Civilisation populations. It also highlights the ways that Indus cropping strategies were adapted to different environments. To do this, it will a) unpack the term 'multi-cropping', b) assess how multi-cropping and diversification have been identified archaeobotanically, c) review prevailing debates about Indus subsistence, and d) interrogate the archaeobotanical evidence for crop exploitation at Indus settlements in different environmental zones. This final section includes new data from northwest India, which illustrates the diverse ways that village farmers engaged in complex food production strategies involving both winter and summer crops before, during and after the first cities existed in the subcontinent. These data advance our understanding of intra- and interregional diversity in practices decisively, and facilitate more nuanced discussions of Indus cropping practices more broadly.

There should be no doubt that world-wide, early farming practices were diverse, and current evidence suggests that the ways in which particular crops were grown was variable (*see* Barker and Goucher 2015). Arguably, bringing precision to the description of cropping systems and ascertaining the degree to which particular practices were widespread or distinctive is essential for properly characterising the specific practices of different farming populations in the past. The overview presented here aims to facilitate the exploration of how more complex definitions of cropping impact our understanding of Indus agricultural strategies, and provide a framework for the identification and discussion of cropping choices elsewhere.

II. What is 'multi-cropping'?

'Multi-cropping' is a term developed by agronomists that can be used to refer to both growing crops in multiple seasons and growing more than one crop in a single season (Gallaher 2009: 255; *see* Andrews and Kassam 1976; Francis 1986). Gallaher (2009: 255) has clarified the definition by arguing that multi-cropping is "the production of two or more crops per year on the same land". Multi-cropping is thus distinct from *mono-cropping* and *mono-culture* where one crop is grown on the same plot for one or more years respectively (Andrews and Kassam 1976; Francis 1986; Butler 1999: Table 24.1).

The principle patterns of multi- (or multiple) cropping were first defined by Andrews and Kassam (1976: Table 1; also Francis 1986; see Butler 1999), who divided it into two forms: *sequential multi-cropping* and *intercropping*. *Sequential multi-cropping* refers to the growing of crops in sequence on the same area of land in the space of one year, in which "the succeeding crop is planted after the preceding crop has been harvested" (Andrews and Kassam 1976: 2). Farmers thus manage one crop in one parcel of land at one time. Andrews and Kassam (1976: Table 1) further subdivided *sequential multi-cropping* as follows:

1. *Double cropping*: growing two crops in sequence;
2. *Triple/Quadruple etc. cropping*: growing three/four (+) crops in sequence; and
3. *Ratoon cropping*: cultivation of regrowth from stubble/roots following initial harvest.

As well as these subdivisions Gallaher (2009: 257) has added a number of extra definitions:

a. *Mono-culture*: the same crop grown in succession (e.g. wheat followed by wheat);
b. *Duo-culture*: successions of the same types of crops (e.g. grain followed by grain; pulse followed by pulse; fodder followed by fodder); and

c. *Poly-culture*: combinations of different types of crops grown for different purposes (e.g. grain followed by fodder).

It is also possible to grow multiple crops simultaneously on the same land, which is referred to as *intercropping* (Andrews and Kassam 1976: 2). As with *sequential multi-cropping*, Andrews and Kassam (1976: 2) suggested that *intercropping* can take several forms:

1. *Mixed intercropping*: growing two or more crops at the same time with no distinct rows or divisions;
2. *Row intercropping*: growing two or more crops at the same time in rows;
3. *Strip intercropping*: growing two or more crops at the same time in strips wide enough apart to allow independent cultivation;
4. *Relay intercropping*: growing two or more crops at the same time during part of their life cycles (i.e.: planting the second before the first has been harvested).

Andrews and Kassam (1976: 3) also noted that *sequential multi-cropping* should be distinguished from 'mixed farming', which they defined as "cropping systems which involve the raising of crops, animals and/or trees"; and 'rotation' systems, in which there is "a repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land", where a cycle of crop growth takes several years. Importantly, *sequential multi-cropping* and *intercropping* are not mutually exclusive, and can both be practised within one overarching strategy, provided due consideration is taken of soil fertility, growth habits and the like. Although these categories and definitions provide a coherent framework for attempting to delineate different cropping strategies, there has only been relatively limited discussion of the complexities of 'multi-cropping' agricultural strategies within archaeology.

III. How are cropping and 'multi-cropping' identified archaeologically?

Archaeology rarely provides direct evidence for cropping practices in the past. Occasionally fields have been identified (e.g. Hall 1982, 1988; Lal 2003: 95-98), but the exposure of such features are not typically the objective of excavation. Analysis of plant remains can be used to identify the crop and associated plant species found at excavated sites, but the plant remains that survive in the archaeological record are typically either discarded residues or material that has been preserved accidentally through waterlogging, desiccation, mineralisation or carbonisation (Dincauze 2000: 332-343). Importantly, the material that is recovered from 'closed' or 'open' contexts within an archaeological settlement (e.g. pit fills, floor surfaces, collapse debris), does not necessarily provide a direct analogue for cultivation practices in the fields. Furthermore, human actions, such as the post-cultivation mixing of crops, can obscure the evidence for actual cropping practices before deposition, and post-depositional mixing can obscure things further. Nonetheless, several attempts have been made to differentiate cropping strategies archaeologically, particularly in parts of Europe, the ancient Near East and Mesoamerica.

In Europe and the Mediterranean there have been attempts to identify 'maslin' cropping, where two crops are mixed for sowing. Amongst other things, maslin cropping is a form of risk buffering (Marston 2013; *see* Halstead and O'Shea 1989), and has been described ethnographically and archaeobotanically (e.g. Halstead and Jones 1989; Jones and Halstead 1995). The medieval western European strategy of sowing wheat and rye together is a maslin system (van der Veen 1995) and matches the definition of *mixed intercropping* outlined above. Several methods have been proposed to identify *mixed intercropping* archaeobotanically, including comparing the relative proportion of grain types and the analysis of the weed assemblages in relation to the weed suites expected of different crops (van der Veen 1995). However, factors such as soil conditions may affect crop mixture decisions, and definitive characterisation archaeologically is hampered by several factors, including the challenge of interpreting a) variation in the proportions of the specific crops that are present, and b) behaviour that sees crops combined in the same pits after harvest (Jones and Halstead 1995). In their ethnographic study on the Greek island of Amorgos, Jones and Halstead (1995) noted that proportions of up to 80% wheat and 20% barley were considered *mixed intercrops* by farmers, but observed that changing conditions over the year may lead to one crop being more successful, thus changing the proportions in a harvested crop (Jones and Halstead 1995; van der Veen 1995). They also highlighted issues of contamination resulting from imperfect isolation of crops from previous growing cycles (Jones and Halstead 1995). Unfortunately, archaeological data is not typically able to reveal such nuances, and van der Veen (1995) has argued that careful statistical analysis supported by proximate ethnographic analysis is likely the only way to distinguish between *mono-crop* and *mixed intercropping* strategies archaeologically (e.g. Jones and Halstead 1995; see Marston 2013). In this regard, it is notable that isotopic studies of samples of wheat and barley from a storage deposit at Vaihingen in Germany have identified examples of both species that shared distinctively low d13C signatures relative to other samples, which suggests that they may have been grown together (Fraser *et al*. 2013).

Different problems beset the archaeobotanical interpretation of 'milpa' agricultural strategies, which is the distinctive Mesoamerican approach to farming involving the 'three sisters': maize (*Zea mays*), beans (*Phaseolus vulgaris* L.) and squash (*Cucurbita* sp.) (Emerson 1953; Ford and Nigh 2009, 2010). These three crops are grown simultaneously in companion planting where each of the species is interdependent. Milpa systems are therefore a specific form of *mixed* or even *relay inter-cropping* and often involve rotation over multiple years (Ford and Nigh 2009, 2010; Postma and Lynch 2012; see also Kennet *et al*. 2012).

Recent studies of weed ecologies and stable isotope ratios of crop grains from the eastern Mediterranean and West Asia have suggested that within an overarching arid to semi-arid environment where irrigation was being practised, wheat and barley were frequently grown in locations that were wetter and drier respectively (Wallace *et al*. 2015: 12). The implication is that wheat received greater levels of water and/or irrigation than barley, either in terms of the quantity of water or the number of irrigations (Wallace *et al*. 2015: 13). In contrast, pulses appear to have been grown in a range of watering conditions, suggesting that their watering was opportunistic (Wallace *et al*. 2015: 14). Although the growing of multiple crops was common across a broad area of the eastern Mediterranean and West Asia, these results confirm that early farmers were extremely cognisant of the water requirements for individual crops, and suggest that crops were consciously sown in specific locations, often in separate fields, where the supply of water could be managed to maximise yield. This system is essentially a form of *mono-culture* and/or *mono-cropping*, though it could also have involved the *intercropping* of pulses (*see* Butler 1999: Table 24.1).

In contrast to these examples of *mono-* or *intercropping* to grow of more than one crop in one season, South Asia and particularly the Indus Civilisation, provide us with an opportunity to examine the dynamics of cropping systems that incorporate both the growing of more than one crop in one season *and* the growing of crops in more than one season.

IV. Indus subsistence and the issue of 'multi-cropping'

The urban phase of the Indus Civilisation (*c*.2600-1900 BC; Fig.1) has long been characterized as a flourishing and culturally integrated early complex society with a number of distinctive attributes, including major urban settlements or cities that are surrounded by substantial fortification walls and/or built on platforms; houses, drains and wells made of mud- and/or fired-brick; and a distinctive material culture assemblage produced using a range of complex craft production techniques (*see* Lal 1997; Kenoyer 1998; Possehl 2002; Chakrabarti 2007; Wright 2010). Since the 1980s, however, there has been increasing recognition that there was a degree cultural and geographical variation across the zone occupied by Indus populations (e.g. Possehl 1982, 1992, 2002; Vishnu-Mitre 1982; Joshi 1984; Meadow and Kenoyer 1997: 139; Weber *et al.* 2010; Wright 2010: 180ff; Ajithprasad 2011; Petrie 2013; Petrie *et al*. in press/2017), and numerous authors have proposed that there was regional variation in subsistence practices (Vishnu-Mitre and Savithri 1982; Chakrabarti 1988; Weber 1999, 2003; Fuller and Madella 2002; Singh *et al*. 2008; Weber *et al*. 2010; Petrie 2013; Petrie *et al*. 2016, in press/2017).

From the beginnings of Indus research, the issue of seasonality and single or multiple season cropping was highlighted. For example, early excavations at the urban settlement of Mohenjo-Daro revealed evidence of the exploitation of wheat, barley (Mackay 1931: 586-7; Luthra 1936) and field pea (Wheeler 1968: 84-5), all of which would have been grown with the support of late summer inundation resulting from Himalayan snow-melt and monsoon rain in the regions to the northeast, complemented by winter rain (*see* Miller 2006, 2015; Petrie in press/2017). Thinking primarily about the areas of Baluchistan and Sindh, Fairservis (1967, 1971) subsequently hypothesised that winter or *rabi* cultivation formed the norm for the Indus region. It has, however, long been argued that summer or *kharif* cultivation was also important (Vishnu-Mitre and Savithri 1982; Weber 1989, 1991). Excavations at the Indus site of Rojdi in Gujarat quantitatively demonstrated that there was more to Indus cereal exploitation than wheat and barley, with the discovery of a sequence of occupation dominated by summer crops; particularly *Eleusine* sp., *Panicum sumatrense*, *Setaria* cf. *pumila* and *Setaria* cf. *italica* (Weber 1989, 1991, 1999). These attestations helped clarify earlier discoveries of what proved to be *Setaria* and *Eleusine* at Surkotada, also in Gujarat, where they were found mixed with a majority of wild plant species (Vishnu-Mitre and Savithri 1982: 214; Vishnu-Mittre 1990: 388-391). The archaeobotanical evidence from these Indus sites in Gujarat was subsequently used to support a model of winter/*rabi* cropping in the 'core' and summer/*kharif* cropping in the 'periphery', where the periphery was regarded as unusual and not representative of the situation across the Indus Civilisation as a whole (Fuller and Madella 2002: 353-5). Fuller and Madella (2002: 355) also suggested that 'core' areas practiced more intensive agriculture, whereas populations in the summer cropping areas utilised more extensive systems.

It is now clear that there are a range of data that suggest that the winter/*rabi* core and summer/*kharif* periphery model is too simplistic. Since the 1980s, it has been argued that Indus populations engaged in multi-cropping (Vishnu-Mitre and Savithri 1982; Chakrabarti 1988: 96; 1995: 50; Weber 2003: 181), particularly in the areas of northwest India where it might have helped with risk buffering (Fuller and Madella 2002: 354-5). However, the archaeobotanical evidence that might support this contention is not definitive, and there has been a lack of quantified archaeobotanical datasets from different locations within individual regions (Petrie *et al*. 2016, in press/2017). Excavations at Harappa have revealed evidence of the exploitation of crops grown in two seasons (see below), with an apparent increase over time in summer crops alongside continued use of winter crops, and this led Weber (2003: 181) to argue that "a complex multi-cropping strategy is evident in all periods of occupation", although the nature of this strategy has not yet been characterised in detail. Winter and summer crops have also been discovered at a number of Indus settlements in northwest India, including Balu, Kunal, Banawali, Farmana, Rohira, Hulas and Sanghol (e.g. Saraswat 1986, 1993; Saraswat *et al*. 2000; Saraswat and Pokharia 2002, 2003; Weber *et al*. 2011; Kashyap and Weber 2013; Weber and Kashyap 2016). However, the precise date at which particular crops were being used at all of these sites is unclear (Petrie *et al*. 2016). Fuller and Madella (2002: 354) have also suggested that the eastern zone of the Indus has evidence of 'double-cropping'—using the term to denote the growing of both winter and summer crops. They argue that this was an extensive approach to agriculture rather than the more intensive approaches used in some of the core regions of the Indus zone (Fuller and Madella 2002: 354).

More recent research has speculated that practices across the entire Indus zone and within individual areas were almost certainly far more varied than was previously apparent, but there have still been limitations to the available data. For example, Singh and Petrie (2009) proposed that variation in local environmental conditions and water supply necessitated variation in farming practices within northwest India. Furthermore, Weber *et al*. (2010) hypothesised differences in agricultural strategy between Harappa, Mohenjo-Daro and Lothal based on variations in environment and rainfall, though neither of these conjectures was supported by systematically collected archaeobotanical data. As Petrie (2013: 93) has noted, however, the true level of variation in practices will only be clear when evidence for the proportional exploitation of individual plant species in different regions and from different settlements within individual regions is widely available. Although there has been a shift in thinking away from simple seasonal dichotomy models, there has been little critical evaluation of the nuances of Indus cropping, and a looseness in the use of the terms 'double' or 'multi-cropping'. Furthermore, there has been limited consideration of the implications that these terms have for discussion of adaptation to the wide environmental variability in the Indus region (Petrie *et al*. 2016, in press/2017). It is thus timely to formulate a coherent theoretical foundation that can be used to characterise extant and future Indus archaeobotanical assemblages. Such an approach will allow us to coherently describe the diversity of Indus cropping strategies that can be detected and the degree to which different types of multi-cropping can be differentiated based on the available data sets.

VI. Differentiating Indus cropping strategies

Archaeobotanical remains have been recovered from only 55 of the 140+ Indus settlements that have been excavated, and systematic flotation and full publication of assemblages remains extremely rare (Fuller and Madella 2002: Table 1; Bates 2016: Appendix 1). The available archaeobotanical evidence demonstrates that across the entire Indus zone, farmers grew a wide range of crops, including cereals, pulses, oilseeds, fibres and fruits (Table 1; see Weber 1999; Fuller and Madella 2002; Wright 2010; Bates 2016), with crops of each major type being grown in summer and winter. It is important to note, however, that variation in the distribution of rainfall and thus the supply of water in general means that it was not feasible to grow all of these crops in all of the regions occupied by Indus populations (Wright 2010: 168; Petrie in press/2017; Petrie *et al*. in press/2017). Miller (2006, 2015) has suggested that in central Punjab, water supply for Indus farmers is likely to have primarily come from inundation (produced by a combination of snowmelt and run-off from the Indian Summer Monsoon) and direct rainfall, while additional water was probably obtained via small-scale irrigation or well/lift irrigation. It is likely that these water supply mechanisms were used across the Indus zone, with differing levels of intensity, depending upon local environmental and climatic conditions (Petrie in press/2017). It is not yet possible to reconstruct the distribution of winter and summer rainfall across the Indus zone throughout the third millennium BC. However, modern instrumental rainfall data suggests that some of the areas inhabited by Indus populations are likely to have received direct winter rain, some probably received direct summer rain, some will have received direct rain from both systems, and others are not likely to have received direct rain from either (Fig.2; Petrie in press/2017; Petrie *et al*. in press/2017; *see* Miller 2006, 2015). Furthermore, the steepness of the rainfall gradients means that there were likely differences in the quantity of direct rainfall that was received, with most areas receiving relatively limited direct rainfall (Fig.2; Petrie in press/2017; Petrie *et al*. in press/2017). Petrie *et al*. (2016, in press/2017) have suggested that variation in local environmental conditions, vegetation, rainfall, and water supply would have necessitated distinctive adaptations for successful farming in different regions, including strategies relying on either winter crops like wheat or barley or summer crops like millet in some areas, or combinations of summer and winter crops.

*Table 1. Major winter (*rabi*) and summer (*kharif*) crops grown by Indus Civilisation populations (adapted from Weber 1999: Table 1, 2003: Table 5.2; Fuller and Madella 2002: Table 2; Wright 2010: Box 6.3; Bates 2016: Tables 4.3, 4.5). 'A' indicates annual and 'P' indicates perennial plant. 'A/P' indicates a plant that can be either. We have separated out longer-lived perennials here as they are not strictly winter or summer crops, though they do flower at specific times.*

Winter (*rabi*) crops		**Summer (*kharif*) crops**	
Cereals			
Barley (*Hordeum vulgare*)	A	Rice (*Oryza* cf. *sativa*)	A
Wheat (*Triticum* sp.)	A	Signal grass millet (*Brachiaria ramosa*)	A
		Sawa millet (*Echinochloa colona*)	A
		African finger millet (*Eleusine coracana*)	A
		Proso millet (*Panicum miliaceum*)	A
		Little millet (*Panicum sumatrense*)	A
		Kodo millet (*Paspalum scrobiculatum*)	A
		Pearl millet (*Pennisetum glaucum*)	A
		Foxtail millet (*Setaria italica*)	A
		Yellow foxtail millet (*Setaria pumila*)	A
		Sorghum millet (*Sorghum bicolor*)	A
Pulses			
Lentil (*Lens* cf. *culinaris*)	A	Black bean (*Vigna mungo*)	A
Pea (*Pisum*)	A/P	Mung bean (*Vigna radiata*)	A/P
Chick pea (*Cicer*)	A/P	Moth bean (*Vigna acconitifolia*)	A
Sweet pea (*Vicia/Lathyrus*)	A	African gram bean (*Vigna* cf. *trilobata*)	A/P
		Horse gram bean (*Macrotyloma* cf. *uniflorum*)	A
Oilseeds			
Linseed/flax (*Linum usitatissimum*)	A	Mustard (*Brassica*)	A/P
		Sesame (*Sesamum indicum*)	A
Fibres			
Linseed/flax (*Linum usitatissimum*)	A	Cotton (*Gossypium arboreum*)	A/P
		Hemp (*Cannabis*)	A/P
		Jute (*Corhorus*)	A/P
Fruits			
		Cucumber/melon (*Cucumis*)	A
Longer lived perennial fruits			
Jujube (*Zizyphus*)	P	Date (*Phoenix*)	P
		Grape (*Vitis*)	P

The variation in water supply across the Indus zone (Petrie in press/2017) has implications for the dynamics of cropping that are explored here, as does the nature and timing of the sowing/growing/harvesting cycle for each crop. It is not yet possible to accurately reconstruct the growing cycles of ancient Indus crops, but assessment of data on modern varieties of the most common crops shows that each has distinctive sowing times, growing periods, water requirements and harvest times (Fig.3, Table S1; *see* Food and Agriculture Organisation of the United Nations, www.fao.org).

There are various challenges to identifying cropping strategies archaeologically, not least the need for good stratigraphic and taphonomic control. The only piece of direct archaeological evidence for Indus cropping is the remains of a field excavated at Kalibangan in northern Rajasthan (Lal 2003: 95-98). The excavators noted morphological similarities between the criss-cross furrow marks in this Early Harappan field and the modern practice of growing chickpea at the edge of mustard crops (Lal 2003: 95-98), though this association was not supported by microscopic archaeobotanical analysis of the field deposits themselves that might have revealed the presence of specific types of phytoliths.

It is fundamentally important to recognise that issues of taphonomy and preservation directly affect the archaeobotanical material that ends up in an archaeological context and whether it survives in the excavated record (Bates 2016: 165-195). Most Indus contexts from which archaeobotanical samples have been collected contain multiple taxa. For example, Weber (2003: 179) has noted that at least three and occasionally more than twenty different species were present in any one deposit at Harappa, and pointed out that there are a range of taphonomic processes that might have led to this mixing of crops in each instance. This observation highlights the fact that many archaeological contexts represent mixed and multiple events, and have the potential to include crop remains that might have been combined during growth, harvest, processing, cooking, waste removal, or even from post- human-use situations such as bioturbation and post-depositional mixing.

Furthermore, the macrobotanical component of an archaeological assemblage is primarily made up of charred remains, and an additional complication comes from the fact that there are different pathways to preservation. Fuller *et al*. (2014) have pointed out that the charred remains are not those that are going to be eaten or used, but are incidental/accidental residues, and as such do not necessarily represent what was grown in the fields. Furthermore, carbonised material may be the product of the burning of animal dung, and while such material will provide evidence of cultivation practices, this need not directly relate to human diet. During the charring process the lighter and more fragile elements such as chaff or small weeds are more likely to be destroyed than the larger, denser elements such as cereal grains, and low temperatures (*c*.350°C) are better for good preservation, whereas higher temperatures will incinerate remains or render them unidentifiable (Boardman and Jones 1990). Whether crops are preserved is also partly dependent on the specific requirements for their use, for instance, hulled millets and pulses like *Vigna* sp. and *Macrotyloma uniflorum* require parching to make the hulls more fragile before removal (Reddy 1997, 2003; Fuller and Harvey 2006). In contrast, many cereals (e.g. wheat, barley and rice), fruits and some oilseeds are rarely likely to meet fire before final use, and some, such as fibre crops, are unlikely to encounter fire at all. Interpretation must thus invariably be bound by a range of caveats.

Much of what can be said about Indus cropping is based on inference. For instance, we know that some crop species cannot be grown together on the same land (Table S1). Although documented as maslin crops in various regions (e.g. Halstead and Jones 1989; Jones and Halstead 1995), barley (*Hordeum vulgare*) and wheat (*Triticum* sp.) may not have been intercropped in close proximity such as in *row* or *mixed intercropping* in less marginal situations because they have different water and fertilisation requirements, and the competitive nature of barley. Thus when both are present, there is some likelihood that they were being grown as separate *mono-crops* (ECOCROP 2016). The need to keep some species apart is more acute. For example, rice (*Oryza* sp.) must be grown separately from sawa millet (*Echinochloa colona*), as the millet is highly competitive and extremely aggressive towards rice (Galinato *et al*. 1999). *Vigna mungo* is not a successful intercrop with rice as it reduces yields (Sengupta *et al*. 1985), though it can be *row intercropped* with *Sesamum* sp., which can also be *intercropped* with millet, as they all have similar water, fertility, soil, salinity and pH requirements. *Sesamum* sp. and rice are not suitable for being *intercropped*, however, because rice has greater water requirements than sesame and shallower soil planting needs. *Macrotyloma* cf. *uniflorum* is usually a *mono-crop* due to the intensity of labour needed in growing it as a *row* or *ratoon crop* of rice and sesame (ECOCROP 2016), but it can be grown as such if more intense effort is put in, as the growing requirements of each of these crops are similar. Furthermore, certain species such as mung bean (*Vigna radiata*), moth bean (*Vigna acconitifolia*) and mukni bean *(Vigna trilobata*) can be perennial and grow over multiple years, but would need permanent patches of land allocated to be grown in this way. Other pulses such as the pea (*Pisum* sp.) and various beans (*Vigna radiata, V. mungo*, *V.acconitifolia*, *V.trilobata*) are climber/prostrate species. Climber species in particular compete with cereal crops for height or space through climbing in a similar fashion to other vine species like bindweed. Although climbing peas grown with cereals have been observed ethnographically (Peña-Chocarro 1999: 167), efforts may well have been made to keep them separate. Alongside these pulses there are also some competitive vegetable/oilseed crops that out-compete other crops. There is less ambiguity with species like *Coccinia* cf. *grandis*, which is extremely aggressive and produces a thick, plant killing blanket of material on a perennial basis, though it is often grown round the edges of fields (Xaygnalis *et al*. 1998). As such, perennial and climber/prostrate species may well have been grown on separate plots of land (*see* Wright 2010: 168) or required extremely careful management and intense labour input to ensure yields of other crops were not affected by their growth. Fruit exploitation can also lead to the allocation of separate parcels of land if grown as orchard crops (*see* Wright 2010: 168). *Ziziphus mauritiana* is a common fruit at Indus sites, but it is not an orchard fruit like dates or citrus fruits, and instead is often found at field edges or even in settlements. As such it does not suggest the setting aside of areas of land specifically for fruit crops, but rather more opportunistic exploitation.

In contrast to these conflicting requirements, *Echinochloa* sp., *Setaria* sp. and *Panicum* sp. share similar ecological and crop processing requirements and can therefore potentially be grown as *mixed intercropping* maslin crops (de Wet *et al*. 1983b). These are hardy and plastic millet species which can survive in a range of conditions. Furthermore, the presence of various annual pulse species such as chickpea and lentil species may indicate that some type of *row* or *strip intercropping* was being carried out alongside crops such as wheat and barley which share similar growth requirements, as they would not require separate parcels of land all year round, and they are advantageous to the growing of cereals because they give nitrogen enrichment to the soil (Agegnehu *et al*. 2006). Several other combinations of crops can be grown as *ratoon cropping* to increase soil fertility (Table S1).

There are also a range of issues relating to the degree to which farmers employed techniques to increase yield as part of intensification or extensification strategies. Intensification is a set of strategies for "obtaining higher productivity over a period of time from the same land than could be obtained by simpler means" (Brookfield 1986: 178; Morrison 1994) and include specialisation, diversification and intensification proper (Kaiser and Voytek 1983), while extensification is increasing yield by using more land over a given time (Halstead 1992, Stevens

1996). Fuller and Madella (2002: 353-355) have suggested that different strategies to increase yields were exploited across the Indus Civilisation, and argued that the areas of the eastern Harappan region taking on a more extensive (i.e. diverse) strategy than the more intensive specialised single-season core strategies. Evidence for the exploitation of different areas for farming has been demonstrated during Rojdi period C (*c*.2000BC; Weber, 1991:135-8) which saw the introduction of wetland sedges.

Only a subset of the archaeobotanical assemblages from Indus settlements has been published in such a way that they can be used to explore differences in cropping strategies. These include Harappa in Pakistani Punjab (Weber 2003), Rojdi (Weber 1989, 1991, 1999) and Babar Kot in Gujarat (Reddy 2003). Reddy's (2003) analysis of material from Oriyo Timbo is also well-published, but she concluded that the crops present were not cultivated by the inhabitants, so this assemblage will not be included here. The evidence for cropping at Harappa, Rojdi and Babar Kot will be contrasted with new data from excavations by the *Land, Water and Settlement* project in northwest India (Fig. 4).

VI.1. Harappa

Systematic archaeobotanical sampling at the urban city-site of Harappa (Fig.4) has shown that a wide variety of crops were being used there over time (Weber 1999: Table 3, 2003: Table 5.2). The agricultural strategies appear to have been dominated by the winter crops wheat and barley, though grains of summer crops, particularly 'little millet' (assumed to be *Panicum sumatrense*), were also recovered from the pre-urban Early Harappan period onwards (Weber 2003; Weber *et al*. 2010; Weber and Kashyap 2016). Using these data, Weber (1999: Table 1) has proposed a hierarchy of crop importance, with cereals forming a first tier, pulses, oilseeds, fibres and fruits forming a second, and a third being comprised of melons and legumes for forage. The diversity of this crop assemblage lies at the core of Weber's (2003: 181) assertion that agriculture at Harappa was characterised by a "complex multi-cropping strategy".

The archaeobotanical assemblage from Harappa is still under analysis, but the data that has been published suggests that although multiple crops were being exploited at Harappa, the growing of crops other than winter cereals is minimal in relative terms. Summer crops, principally *Panicum* sp. millet, but also pulses, cotton and fruits, have a ubiquity of 9% in the Early Harappan period, and increase to appear in 19% of Mature Harappan and 47% of Late Harappan samples (Weber 2003: Table 5.3.a); with ubiquity being a measure of the percentage of samples from which specific taxa were recovered. These data suggest that over time, summer crops appeared in more contexts. However, these ubiquity statistics have the potential to be misleading, as Weber (2003: Table 5.3.c) has noted that in the Early Harappan period summer crops only equate to 2% of the overall charred crop assemblage in terms of relative abundance, and this only increased to 4% in the Mature Harappan and 7% in the Late Harappan periods. In parallel with this minor increase in the relative abundance of summer crops over time, there *was* a marked decline in the relative abundance of winter crops, from 96% to 83% and then 77%, but the main source of increase is in the 'weeds/unknown/other' category (Weber 2003: Table 5.3.c).

Interpreting the significance of these data is further complicated by plant morphology, particularly the fact that while *Panicum* sp. millet produces many more seeds per head than either wheat or barley, millet seeds are smaller and less calorific per grain (Bates *et al*. 2016b). Therefore, while summer crops were present at Harappa throughout the sequence, it is arguable that the preserved quantities of seeds indicate that they were a relatively minor component of the overarching crop assemblage, particularly in contrast to the exploitation of wheat and barley. It is actually feasible that the presence of such low quantities of summer crops indicates the actual transport of grain to Harappa from farther afield rather than local exploitation, though this suggestion would be invalidated evidence for the processing of summer crops at the site is preserved (Petrie *et al*. 2016).

The relative abundance of winter and summer crops at Harappa thus suggest that if it was practised at all, *sequential multi-cropping* may only have ever formed a relatively minor component of the overall cropping strategy, even in the Late Harappan period. The winter crops wheat (*Triticum* sp.) and barley (*Hordeum* sp.) are by far the most commonly found taxa in all periods, though there was certainly a shift in which of these two crops was dominant over time, from barley to wheat and then back to barley (Weber 2003: Table 5.3.c). The presence of these summer crops and the increase in the use of summer and drought tolerant crops over time supports Weber's (2003: 181-9) assertion that there was increasing diversity over time of the crops exploited at Harappa, potentially related to the desire to create a more dependable food supply throughout the year. The details of the associated weed suite and the contextual details of the archaeobotanical assemblages are not yet available, so at present it is not possible to conduct a more complex analysis to assess whether the wheat and barley were part of a 'within season' *intercropping* system, or they were being grown as parallel *mono-crops* in separate fields (*i.e.* a two-crop strategy; *see* Jones and Halstead 1995). The presence of brassicas ('mustard') and lentils does, however, suggests that some type of *intercropping* involving pulses was possible, though the preserved quantities of each suggest that this was likely small in scale.

VI.2. Rojdi

Weber's (1989, 1991, 1999) analysis of material from the small Indus settlement site of Rojdi (Fig.4) also demonstrated the use of a wide range of crops, but highlighted a very different cropping pattern to that seen at Harappa, with a summer crop-dominated assemblage based on the exploitation of millets and other summer crops. Despite this dominance, at no point does the assemblage consist entirely of crops grown in one season, and the proportionality of the crop assemblage remained fairly constant over the sequence. In Phase A (*c*.2500-2200BC) summer crops formed *c*.98% of the crop assemblage with *Eleusine* sp. millet being the most dominant crop, although this identification of *Eleusine* have since been questioned (Fuller 2006, 2011), alongside some *Panicum miliare*, with a very small winter crop component of barley; in Phase B (*c*.2200-2000BC) summer crops were again the most dominant, increasing slightly to 99% of the assemblage, with *Panicum miliare* being the most dominant, and a very minor winter component (1% of the crops) formed of *Brassica* sp. (mustard); and in Phase C (*c*.2000-1700BC), different millets in the form of *Setaria glauca* and *Setaria* cf. *italica* became a component of the summer crop assemblage. As with *Eleusine*, identifications of *Setaria italica* have since been questioned (Fuller 2006, 2011; Stevens *et al*. 2016), which proportionally dropped to 91% of the overall assemblage as winter crops increased to 9% of the overall crops, and increased in the range of species present, as lentils, *Lathyrus* sp., *Vicia* sp. and flax (*Linum* sp.) were present along with the mustard (data acquired from converting densities into percentages of crop assemblage from Weber 1989: 270, Table 18; 299, Table 23; 315, Table 29; 366-7, Table 33). Although crops from two seasons were present, the cropping strategies in Rojdi Phases A, B and C were almost entirely focussed on the summer growing season. A slight decline in the role of summer crops was seen in the final mixed Late Harappan/Early Historic material of Phase C/D, with a reduction to 87% of the overall assemblage, and a mix of all three millet genera being attested, along with barley, *Lathyrus* sp., *Vicia* sp. and flax (data converted from density table in Weber 1989: 366-7, Table 33). Weed species and a brief discussion of their ecologies are published from this site, but there is little consideration of the significance those ecologies have for understanding cropping strategies beyond their inclusion in the seed morphology descriptions (Weber 1989: 194ff.).

It is arguable that while the focus on the summer season cropping continued throughout the sequence at Rojdi, in terms of relative abundance and proportions, slightly more *sequential multi-cropping* might have been practised at Rodji than at Harappa. Looking at the species, in Phase A, *Eleusine* sp. millet was the most commonly found crop and formed the majority of the samples in which it is found, which could indicate *mono-cropping*. However, Weber (1989) also observed that *Eleusine* sp. was commonly found with some *Panicum miliare*, which could suggest *intercropping*, though as he notes "it is unclear whether the occurrence of these seeds together represents mixing at times of cultivation, processing or use" (Weber 1989: 275). In Phase B, however, there was a change to *Panicum miliare* as the dominant crop, which could again indicate *mono-cropping*, though it is unclear whether the millet occured only with weeds or with other crops. In Phase C there was a further change, with *Setaria* sp. becoming dominant. Weber (1989) noted the mixing of *Setaria* cf. *glauca* and *Setaria* cf. *italica*, and pointed out that each species has different management needs, with *S. glauca* preferring little management while *S. italica* needs heavy weeding. The difference in these requirements suggests that *strip inter-cropping* or *mono-cropping* of millets in separate fields was practised in Phase C. In Phase C/D, a different pattern was again seen in which three millets were commonly found. These millets have similar husbandry and processing requirements and therefore could have been grown together, but there is little information on how commonly they are found mixed in individual samples, which makes it difficult to differentiate whether they were *mono-* or *inter-cropped*.

VI.3. Babar Kot

Further evidence of the summer crop-dominant cropping regime has also been documented at other Gujarati Harappan settlement sites such as Babar Kot (Fig.4; Reddy 1994, 2003), in the semi-arid region of Saurashtra. Three 'occupations' attributed to the Harappan period were found dating to the late Mature Harappan (I) and transitioning into the Late Harappan periods (II, III) (Reddy 1994, 2003). The archaeobotanical crop assemblage shows an even more intensive focus on a summer cropping regime than that seen at Rojdi, with: summer crops forming 94.3% of the crop assemblage in Occupation I with a minor component of lentils forming the other 5.7% of crops; 99.7% in Occupation II, the other 0.3% formed by lentils, *Lathyrus* sp. and flax; and 99.8% in Occupation III, with the other 0.2% of the crop assemblage formed of a minor inclusion of flax, *Brassica* sp. (*cf*. mustard), lentils, *Vicia* sp. and *Ziziphus* sp. (data obtained by deriving percentages from the densities in Reddy 2003: 122). Weed species are published from this site (Reddy 1997, 2003), but statistical analysis of the relationship between the weed ecology and cropping practices has not yet been attempted.

Millets, including *Panicum miliare* and *Setaria italica*, were the main crops throughout the sequence, with the dominant species being dependent on period of occupation and context (Reddy 2003: 122, 129-130). In Occupation I, *Panicum miliare* (Reddy 2003: 122) was the only millet present, so it is likely that it was grown as a *mono-crop*. In Occupation II there was a notable change with *Setaria italica* forming 79.88% of the millet assemblage while *Panicum miliare* formed 19.11% (Reddy 2003: 122), although identifications of *Setaria italica* have since been questioned (Fuller 2006, 2011; Stevens *et al*. 2016). Reddy (2003: 129-30) noted that *Setaria italica* was found in separate pits from *Panicum miliare*, and also pointed out that there are different weed suites associated with these two crops. The lack of evidence for the mixing of these two species in any one context makes it likely that both were grown as *mono-crops* in different fields. In Occupation III *Setaria italica* formed 92.5% of the millet assemblage, and 'seed pockets', or distinct clumps of seeds were also found (Reddy 2003: 128-9), again suggesting that *mono-cropping* focused on one cereal species was being carried out.

VI.4. *Land, Water, Settlement* project sites

The *Land, Water, Settlement* project has excavated a number of Indus village settlements situated across northwest India (Singh *et al*. 2009, 2010, 2012a, 2012b, 2013a, 2013b; Petrie *et al*. 2009; Petrie *et al*. in press/2017). Flotation samples have been analysed from Early, Mature and Late Harappan period deposits at five sites: Dabli-vas Chugta, Burj, Masupdur VII, Masupdur I, and Bahola (Table 2; Bates 2016; Bates *et al*. 2016a, 2016b, in press; Petrie *et al*. 2016, in press/2017). Although all located in northwest India, each of the settlements excavated by the *Land, Water and Settlement* project was situated in a distinctive environmental and ecological zone (Table 3), which potentially enabled and constrained the cropping practices of local farmers.

Table 2. Phases of occupation excavated at different Land, Water and Settlement *project sites discussed here.*

Code	*Name*	*Trench*	*Early Harappan*	*Mature Harappan*	*Late Harappan*	*Painted Grey Ware*	*Black Slip*	*Early Historic*
DVC	Dabli vas Chugta	ZA6		X				X
DVC		ZI7		X				
BRJ	Burj	ZA2	X			X		X
BRJ		ZG9	X			X	X	
MSD VII	Bhimwala Jodha	YA2	X	X	X			
MSD VII		YB1	X	X	X			
MSD I	Sampolia Khera	XA1		X	X			
MSD I		YA3		X				
MSD I		XM2		X				
BHA	Bahola	AB1			X	X		X

Table 3. Modern environmental context of the Land, Water and Settlement *project sites. Data compiled from Fagan and Townsend 1915; Punjab District Gazetteers 1918; Spate* et al. *1967; Pascoe 1973; Bhatia and Kumar 1987; Weber 2003; Yadev* et al. *2005; Kottek et al. 2006; Department of Agriculture 2007-8a, 2007-8b, 2007-8c; Wright 2010; Singh* et al. *2010, 2012b; Neogi 2013; iiss 2014; weatherbase 2015.*

	Dabli vas-Chugta	*Burj*	*Masudpur I & VII*	*Bahola*
Köppen-Geigger Climatic Classification	Transition: hot arid steppe to hot arid desert	Hot arid steppe	Transition: hot arid steppe to hot, dry winter, hot summer	Hot, dry winter, hot summer
Landscape	Flat alluvial plains with sand dunes	Flat alluvial plains with occasional dunes	Flat alluvial plains with occasional dunes	Flat alluvial plains with occasional dunes
Proximate landforms	Thar Desert	N/A	N/A	Seasonal nullah
Site location	Margin of flood zone	Margin of flood zone; Slightly raised sandy landform	Far from river flood zone; (VII on fossil dune) (I on bedded sand)	Margin of flood zone; Natural mound
Av. Annual Temp (ºC)	25.6	25.3	25.2	24
Av. Summer Temp (ºC)	31.7	29.2	30.5	29.2
Av. Winter Temp. (ºC)	19.6	19.4	18.5	18.7
Av. Hottest temp. (ºC)	35	34.5	34	32.4
Av. Coldest Temp. (ºC)	13.9	13.9	13.6	13.5
Av. Annual rainfall (mm)	304.4	361.5	490.7	675.9
% Summer rainfall	88%	88%	86%	88%
% Winter rainfall	12%	12%	14%	12%
Av. No. of days of rain annually	22.5	24.2	25.8	27.5
No. of rainy days (S)	18.4	18.4	20.4	20.8
No. of rainy days (W)	5.7	5.6	5.4	6.7
Av. groundwater depth (m)	1.6 – 25	3 - 10	3 - 10	Max. 7.6
River system	Ghaggar	Ghaggar	-	Yamuna
River seasonality	Summer flooding	Summer flooding	Limited summer flooding	Perennial with summer flooding
River flow (million acre feet)	0.5 - 2.5 MAF	0.5 - 2.5 MAF	0.5 - 2.5 MAF	3.19 MAF
% River flow Summer	100%	100%	100%	80%
% River flow winter	0%	0%	0%	20%
Distance from river (est.)	<0.5km (Ghaggar palaeochannel)	<0.5km (Ghaggar palaeochannel)	>50km (Ghaggar palaeochannel)	<0.5km nullah c.25km (Yamuna)
River temperament	Low energy flooding	Low energy flooding	Low energy flooding	High energy flooding
Soil texture	Sand with silt-clay below	Silt-loam, some sand	Sand-loam, some clay-loam	Sand-loam
Soil pH	8.3 – 8.4 Weakly alkaline	10.24 Alkaline	9.04 Weakly alkaline	6.5-8.6 Neutral - weakly alkaline
Soil nitrogen	Low	Medium	Low-medium	Low
Soil phosphates	Low	Medium	Low-medium	Low
Soil potassium	High	Medium	Low-medium	High
Soil Salinity	Often High	Low	Low	Low

Using weed ecology to understand cropping practices

Different crop and weed seeds have specific ecological requirements (SI.1, Tables S1-S2i-xi), so the presence and absence of specific crops and weeds, and the combinations in which the two appear, provide insight into their growing conditions and hence the cropping practices that local farmers used in each context to produce them. A range of factors affect what will grow, where it will grow and whether it will grow with other plants, including soil pH and fertility, plant fertility and water requirements, and if the conditions are optimal, more plants will grow (Stevens 1932, 1957). Ellenberg (1950) and van der Veen (1992) have also argued that the type of crop can influence the associated weed flora because of aspects such as leaf shade and rhythm of growth. Given that we know little about growing conditions in the past, the ecology of plants, especially weeds, is important for understanding what the environment was like in and how it may have been altered by human action. There are numerous archaeological studies that have explored weed ecology (e.g. Jones 1981, 1984, 1985, 1986; van der Veen 1992; Stevens, 1996), but each has used different methods. Three main methods have been used: phytosociology, autecology and FIBS; with each having associated benefits and problems (Bates 2016: 117).

Phytosociology is the classification of the associations of species into groups' representative of the ecological conditions (Ellenberg 1974). It has been applied in archaeology especially in Central Europe where a large number of modern phytosociological models have been developed (e.g. van der Veen 1992; Stevens 1996, 2003), but comprehensive modelling of phytosociological groups is lacking for agricultural systems in South Asia. Autecology looks at the relationship of each species to its environment, rather than the relationship between plants (Ellenberg 1988). Autecology studies are uncommon in South Asia (Rao & Nagamani 2010), and those that have been carried out have focussed on individual species (e.g. *Eleusine indica*; Singh 1968; Singh and Misra 1969; *Cyperus rotundus*; Ambasht 1964; *Chenopodium album*; Misra 1969). These studies have, however, often focused on species that have a major impact on modern agriculture, rather than a systematic study of the range of species present. FIBS (Functional Identification of Botanical Surveys), or functional ecology, is an approach to plant ecology (see Garnier *et al*. 2016) that has been adopted by archaeobotanists as a response to the problems of local ecologies and the patchy nature of studies (Charles *et al*. 1997). This approach proposed the use of 'functional attributes' from plants such as canopy height, leaf height, root depth and type, seed bank formation and the reproductive habits of plants to identify human actions such as irrigation, soil disturbance, and manuring (Charles *et al*. 1997; Bogaard *et al*. 1998, 1999; Jones *et al*. 2000, 2010). However, as Jones *et al*. (2000) have noted, there is not necessarily a direct link between some functional attributes and single activities, for example root depth could be an indicator of either water stress or soil disturbance. Also, although it has been used in Europe and the ancient Near East (e.g. Charles *et al*. 1997; Bogaard *et al*. 1998, 1999; Jones *et al*. 2000, 2010), the FIBS approach has not been demonstrated through application to archaeological issues elsewhere in a systematic way. Furthermore, for our purposes, it is notable that no FIBS surveys have yet been carried out in South Asia or applied to agricultural methods that are of interest to South Asian archaeology. Future field research that explores the functional adaptation of weeds in the South Asian context are clearly required in order to address these issues specifically.

Given the limitations of the extant data, a method combining autecology and a FIBS-type approach of exploring some of the physical aspects of the plant, has been developed for exploring the weeds to look at questions of crop management in the Indus context (Bates 2016: 119-120). This approach is adapted from the one used by Stevens (1996) in the Upper Thames Valley, where he combined both autecology data and information on other aspects such as seed bank and root depth. As no single comprehensive autecology study for South Asia or the Indus Civilisation region is available, we have followed van der Veen (1992) and Stevens (1996) in using a combination of data sources such as floras and published autecology studies, which helps with consideration of a number of issues. For example, the question "where were the plants (weeds and thus by proxy crops) growing?" can be approached by considering soil structure, soil pH, and soil moisture; the question "how often were the fields being used?" can be approached by considering the reproductive techniques of weeds, non-arable weeds, and nitrophobic species; the question "were manuring or drainage techniques being used?" can be approached by considering nutrient indicator species; the question "was tillage being used?" can be approached by considering reproductive techniques, seed dormancy, and root type; and the question "what weeding practices were used?" can be approached by considering seed dormancy and germination time (Bates 2016: 120).

The archaeobotanical material presented below includes the macroscopic remains of grains of seed crops and weed species from five of the settlements excavated by the *Land, Water and Settlement* project (SI.2, Tables S3-S4). These sites are discussed from west to east, starting with the site likely received the least annual direct rainfall (Dabli vas Chugta). It is important to note at the outset that in general crops and weeds appeared in relatively low abundance at these settlements, which appears to be a product of poor preservation in alternating wet/dry conditions and sites with shallow depth of deposit (Bates 2016; Petrie *et al*. 2016). The significance of specific combinations of crops and weeds that have been recovered from each of these sites will be discussed below, and this will be supported by consideration of the specific ecological requirements of various crop and weed species.

Dabli-vas Chugta

The site of Dabli-vas Chugta lies 7km from Kalibangan in Hanumangarh District, Rajasthan (Fig.4), and although initially believed to have been occupied during the Early Harappan period (Singh *et al*. 2012b), radiocarbon dates now suggest that it was occupied during the early phase of the Mature Harappan period. The crop assemblage is diverse, and includes cereals, pulses, fruits and oil seeds, though cereals dominate (Table S5). Winter crops form the majority of the crop assemblage at 58.95% and summer crops make up 24.91%, with the remaining 11.52% being unidentified/unidentifiable cereals or pulse fragments that cannot be attributed to a season and 4.61% belonging to fruits (Table S5; Bates 2016: 195). Barley (*Hordeum vulgare*) was the most common crop, both in terms of abundance, ubiquity and density, and prefers dry soils (Table S5). In most contexts, barley was the only crop present, though in some of the earliest levels it was recovered alongside some millets, including *Setaria* sp. and *Panicum* sp. (Bates 2016: 134), which are both suited to poor soils (in terms of fertility and moisture), and are tolerant of both flooding and drought (Table S1). While present, other crops such as wheat (*Triticum* sp.), lentil (*Lens* cf. *culinaris*), mustard seed (*Brassica* sp.), and jujube berry (*Ziziphus mauritiana*) were not common (Table S5), and presumably less important in the cropping strategy, though significant quantities of indeterminate Fabaceae were present.

In the weed assemblage (Table S6), only *Avena* sp. could be definitely attributed to the winter growing season, though *Chenopodium* cf. *album* was also present and could also have been a weed of the winter season. *Avena* sp. is a common weed of barley and wheat, and given the dominance of *Hordeum vulgare*, its presence is not surprising. *Avena* sp. is most commonly seen in low water moisture conditions and acidic soils, and the presence of *Chenopodium* cf. *album* indicates high nitrogen conditions (*see* Table S2ii,iv,v), so the two in combination suggest that there was a range of soil fertility in the fields around Dabli-vas Chugta. Although both species are annuals neither responds well to tillage, so their presence might indicate that there was not a high level of soil disturbance. Several summer season weeds were attested (Table S6), which have a range of ecological preferences (Tables S2, S7). Most prefer wet soils though the proportion of flood and non-flood tolerant species is roughly similar, and some drought tolerant species were also present (Table S7). This combination of weeds implies that water supply was inconsistent in summer, including both flood and drought. Weeds that can tolerate any soil conditions or only specifically sandy soils were noted, and extensive changes to the soil matrix, fertility and pH are not evident (Table S7), which may suggest that heavy soil disturbance was not occurring. This pattern is supported by the life cycles of the weeds, as although the majority were biennial, the main reproduction method was through both a seed bank and rhizomes, again suggesting a lack of much soil disturbance (Table S7). The adaptability of the summer crops and the range in tolerances seen in the summer weeds suggest that summer cropping could have been carried out on a broad range of land types around the settlement.

The seasons of the crops and the growing conditions indicated by the crops and the weeds at Dabli-vas Chugta suggest that *mono-cropping* of barley dominated the cropping strategy, possibly with some *sequential multi-cropping* involving millet in the earliest phases. Wheat might have been grown as an additional *mono-crop*, and it may well have been grown in separate fields to the barley, as they have different water and fertilisation requirements, and because of the competitive nature of barley. It is possible that the millets were grown as *mixed intercrops* (*see* de Wet *et al*. 1983a). Exploitation of pulses and fruits appears to have been relatively limited, though their presence suggests that there might have been some *intercropping* of winter pulses with barley, wheat or both. Such pulses and fruits may well have been grown at the edges of larger fields, and the intercropping of *Hordeum vulgare* and *Brassica* sp. such as *Brassica juncea* and *nigra*, and also with *Lens culinaris* is common today.

Burj

The site of Burj is a one-hectare village settlement site situated in Haryana, India (Fig.4), which was established in the Early Harappan period, but then appears to have been abandoned until the considerably later Painted Grey Ware period (Singh *et al*. 2010). The Early Harappan period archaeobotanical assemblage from Burj was poorly preserved, with a large proportion of crops being of uncertain seasonality (Table S8), which makes it difficult to analyse these remains in terms of cropping strategies. Notably, no summer crops were identified in the Early Harappan period deposits, and only *Hordeum vulgare*, the indeterminate category *Hordeum/Triticum*, and *Ziziphus* sp. were identifiable, suggesting that barley and jujube fruits were the dominant Early Harappan period winter crops (Table S8). The preservation conditions at Burj in the Early Harappan period that were noted for the crops also hold for the weeds. Only one weed type was noted; an indeterminate small grass, and as such nothing can be discussed in terms of weed ecology for Early Harappan Burj.

Archaeobotanical preservation in the PGW period contexts was notably better, and a very different pattern emerges. There is considerably more diversity in the crop species present, including cereals, pulses and fruits (Table S9). In contrast to the Early Harappan deposits, summer crops form the largest proportion of crops at 83.25% in the PGW period (including *Echinochloa colona*, *Setaria* cf. *pumila* and *Panicum* sp), with winter crops forming only 9.91%, tree/orchard fruits forming 5.9%, and uncertain seasonality crops forming 0.94% of the assemblage (Table S9). These proportions suggest that while there was a focus on summer crops, some *sequential cropping* was also being carried out in the PGW period, as seen at Rojdi Phase C/D. One cereal crop was again dominant, though in the PGW period it was *Echinochloa* sp. millet, which was found predominantly on its own or with small quantities of other small grained millets (Table S9; Bates 2016: Table 7.5). It is notable, however, that small quantities of winter pulses were attested, including chickpea and a possible type of sweet pea (Table S9).

Within the PGW period weed assemblage, no winter weeds were identified, so it is not possible to make comparisons between seasons at the settlement. This apparent absence of winter weeds is interesting as some winter crops were present, suggesting that either weeds were removed during crop processing, and also leaves open the possibility that winter grain was imported from elsewhere. However, the presence of winter cereal chaff phytoliths and

Pooideae leaf/stem elements (Bates 2016; Bates *et al*. 2016b) suggests that early stage crop processing as well as late stage processing was occurring on or near the site. It is thus less likely that these cereals were being imported to the site as a whole cereal ear including stem and stalk and instead were being grown in the vicinity of the site. The lack of winter weeds could relate to differential pathways to preservation to summer weeds (for example, not reaching charring at the same rate) or processing taking place elsewhere at the site.

A number of summer weed species were present at Burj (Table S10), and display particular ecological preference indicators (Table S11). The weed preference for moist to dry soils and a low tolerance for flooding suggest that irrigation may not have been utilised, but the fact that most weeds had a low drought and flooding tolerance suggests that there may have been some control of the water regime. This pattern is interesting in relation to the proximity of Burj to the seasonal river and the geoarchaeology that has been carried out at the site (Neogi 2013), both of which suggests the high potential for low intensity but regular flooding. It also implies that agriculture in the summer may have been carried out either away from the areas affected by overbank flooding or was more likely carefully managed to prevent both flood and drought conditions. The summer weeds can tolerate any soil conditions or only specifically sandy soils, with indications of a low nitrogen system and moderate fertility. There appears to be a lack of extensive changes to the soil matrix, fertility and pH, suggesting that heavy soil disturbance was not occurring. This pattern is again supported by the life cycles of the weeds, where although the majority were biennial, the main reproduction method was through both a seed bank and rhizomes. This weed ecology fits fairly well with the limited ecological data available for the three main summer crops, *Echinochloa colona*, *Setaria* cf. *pumila* and *Panicum* sp (*see* Table S1). The lack of high-intensity water management indicated by the weeds fits well with these millets, as does the implied moderate soil fertility and the range of soil textures. They can also grow in a range of conditions from dry lands to marshy situations, and are competitive (Galinato *et al*. 1999), fitting well with the models of past land use for the area (Table 3).

The co-occurrence of winter cereals and perennial but summer flowering fruits in the Early Harappan deposits could be suggestive of some form of 'mixed farming' (Andrews and Kassam 1976: 3), with the fruit trees potentially growing at the edges of cereal fields.

Unfortunately, the weeds provide little insight into this situation. During the PGW period, crop proportions suggest that *mixed intercropping* of millet was predominant in the summer season, but that the overarching strategy involved *sequential multi-cropping* when the winter season crops are taken into consideration. It is notable, however, that no macro remains of winter weeds were attested despite the phytolith evidence suggesting their presence (Bates 2016, Bates *et al*. 2016b). Even more so than at Dabli-vas Chugta, exploitation of pulses and fruits at PGW period Burj was limited. *Intercropping* of some of the pulses is possible. *Cicer* sp. and *Lathyrus* sp. are annual legumes, and in north-west South Asia they are often intercropped with barley and wheat, usually in *row intercropping*, which helps with nitrogen enrichment of soil (*see* Agegnehu *et al*. 2006). In contrast, *Pisum* sp. is a climber/prostrate annual, and would have been difficult to intercrop with cereals as it would compete for height, so separate parcels of land for growing peas are therefore a possibility. *Vigna radiata* is perennial when wild but annual when domesticated, so may not have needed separate land over multiple years. However, it is often shrubby in appearance or climbing, suggesting that it might need a separate parcel of land, though this could take the form of a carefully managed *strip intercrop*, which would improve the nitrogen contents of soil. Jujube trees may also have been mixed farmed at the edges of fields (*see* Andrews and Kassam 1976: 3).

Masudpur VII

The site of Masudpur VII is a 1-hectare village-sized settlement that is situated 18km from the Indus city of Rakhigarhi in the modern state of Haryana, India, and was occupied in the Early, Mature and Late Harappan periods (Petrie *et al*. 2009, 2016; Fig.4). The crop assemblage from Masudpur VII was mixed, including a range of cereals, pulses and fruits (Table S12). In the Early Harappan period at Masudpur VII, there was clear evidence a more mixed cropping system than seen at other contemporaneous sites, with 24.68% winter crops and 58.87% summer crops, 7.59% tree/orchard fruit and the final 8.86% made of unidentified seasonality crops (Table S12). Two crop species dominated, one winter and one summer: wheat and *Echinochloa* sp. millet. *Macrotyloma* cf. *uniflorum* and *Ziziphus mauritiana* were, however, present in significant quantities, and rice and other legumes (e.g. *Vigna radiata* and *Pisum* sp.) were also attested.

No winter weeds were attested in any of the phases of occupation at Masupdur VII, but a range of summer weeds were attested in the Early Harappan assemblages (Table S13). The ecological preferences of the Early Harappan summer weeds (Table S14) suggest moist, sometimes wet, soil conditions and some flood tolerance, which indicates that some control of water supply may have been carried out to avoid desiccation, though there is no evidence that this involved irrigation. This perhaps suggests active management of rainfall induced flooding/inundation. No particular soil was preferred, and evidence for leaching is low as the weeds preferred alkaline soils and moderate fertility. There was a lack of Chenopodiaceae weeds, but some Fabaceae weeds were present, perhaps suggesting low nitrogen levels. Low nitrogen levels fits with the soil model for the area (Table 3) and perhaps suggest there was no leaching caused by heavy soil disturbance. The majority of the weeds were biennial, which also supports the idea of low soil disturbance, as does the presence of both vegetational and seed bank reproduction. As such, it appears that limited management was needed to produce a good yield.

The proportions of wheat and *Echinochloa* sp. millet and the growing conditions indicated by the crops and the weeds at Early Harappan Masudpur VII potentially indicate that although there was a summer focus, *sequential multi-cropping* was being carried out. The presence of both rice and *Echinochloa* sp. suggests that these crops are likely to have been grown as spatially distinct *mono-crops* on separate land in summer. The climber/prostrate nature of pea (*Pisum* sp.) suggests that it is likely to have been grown as a *mono-crop* on separate land in separate seasons (Tables 1, S1). This is also likely for *Macrotyloma* cf. *uniflorum* due to the intensity of labour needed in growing it as a *row* or *ratoon* crop of rice and sesame (Table S1; ECOCROP 2016). *Coccinia grandis* would also have required either separate spaces, or more likely, would have been grown at the edge of fields, and the same is likely for fruit trees. Some *Cicer* sp., *Vicia/Lathyrus* and indeterminate oil/fibre seeds were present, and thus some *intercropping* is possible. Although it is difficult to be precise, the combination of crops present indicates that there must have been considerable complexity of the crop management strategy throughout the year at Early Harappan Masudpur VII.

In the Mature Harappan period the assemblage as a whole remains mixed and includes cereals, pulses and fruits, all in significant quantities (Table S12). Two crops again dominated, but this changed to barley and *Echinochloa* sp., and there was a shift towards winter crop dominance (52.38%), with summer crops forming 31.75% and tree/orchard fruits making up a slightly larger proportions than in the Early Harappan at 12.7% (unknown seasonality crops continue to form a small part of the assemblage at 3.17%) (Table S12). However, rice grains were not attested, and *Echinochloa* sp. was the only millet species. Also, peas and lentils, which are winter pulses, were not present, but a range of summer pulses were attested, including *Vigna radiata*, *Vigna mungo* and *Macrotyloma* cf. *uniflorum*, and *Ziziphus mauritiana* was also present.

As in the Early Harappan period no winter weeds were found, but the presence of both early and late stage processing waste and phytoliths from winter crops implies that winter crops were likely to have been grown close to the site. The ecological preferences of the summer weeds in the Mature Harappan assemblage (Table S16) show some differences, with slightly wetter conditions showing more flood tolerance in evidence, perhaps indicating more water management. The higher proportion of drought tolerance, however, also suggests that the range of water conditions could have been increased in this period. Weeds that can tolerate any soil conditions were again noted, but there were slightly higher proportions of sand-preference weeds when compared with the Early Harappan period. Combined with wetter conditions the presence of sand-tolerant weeds could suggest greater leaching potential. Indeed, more neutral and acid soils were indicated in the Mature Harappan period, but the majority of weeds indicating specific soils suggested alkali or neutral soils were being used, and the soil fertility was moderate. Neither Fabaceae weeds nor Chenopodiaceae weeds were noted in this period in the weed assemblage, perhaps suggesting that the conditions remained moderate in nitrogen, which in turn suggests that there may have been little soil disturbance. The lack of purely annual species and species producing by seed bank might, however, indicate that ard tillage was being utilised, leading to light soil disturbance (*see* Stevens 1996).

The seasons of the crops and the growing conditions indicated by the crops and the weeds suggest that a *sequential multi-cropping* strategy was utilised during the Mature Harappan phase at Masudpur VII, involving a *duo-culture* of summer and winter cereals. In the summer *Echinochloa colona* may have been *intercropped* with some of the pulses (e.g. *Brassica* sp.), while other pulses are likely to have been grown as *mono-crops* (*Macrotyloma* cf. *uniflorum* and *Vigna* *radiata*), potentially on perennially allocated land for mung bean if it was a non-domesticated form. Fruit trees will have also required their own space, but the only one that could be identified was *Ziziphus mauritania*, as at all sites, and as such it seems unlikely that orchards were present and field boundary trees were being exploited. Interestingly, fewer varieties of crops appear to have been used during the Mature Harappan period, perhaps indicating deliberate choice to minimise diversity and focus on particular crops (Table S12) (Bates and Petrie in prep).

Only three samples were available to study for the Late Harappan period at Masudpur VII and as such it is questionable as to how representative these are of the Late Harappan agricultural strategy at the settlement. The material from these samples suggests that there was a return to the diversity of the crop assemblage and a shift back to the dominance of summer cropping (80.17%), with winter crops forming 11.2%, tree/orchard crops 3.45% and unknown seasonality crops 5.17% (Table S12). *Echinochloa colona* continued to be grown, and rice reappears in the summer cropping regime, but the overall assemblage is dominated not by a cereal but *Coccinia* cf. *grandis*, which is a type of gourd and a possible famine food (Table S12). This finding could resonate with evidence for dietary stress and disease at Harappa and the end of the Mature and into the Late Harappan phases (Robbins Schug *et al*. 2013a, 2013b, Robbins Schug and Blevins 2016), and also indications that there was a weakening of the Indian Summer Monsoon in northwest India *c*.2200 BC (Dixit *et al*. 2014), which is a local northwest Indian manifestation of a much more widespread phenomenon (Madella and Fuller 2006; MacDonald 2011; Berkelhammer *et al*. 2012; Giosan *et al*. 2012). It could, however, be a taphonomic issue as *Coccinia* cf. *grandis* was found in one of the three contexts where little else was recovered, and therefore might suggest that several gourds were burnt in a single event, which is likely to skewed the crop proportions when compared to the other two multiple event type contexts found (see Fuller *et al*. 2014 for discussion of the types of contexts that can be found on sites; following Hubbard and Clapham 1992). It could therefore be a case of low sample size being affected by an unusual sample type and/or event rather than an indication of a major impact on diet and agricultural choices.

Again there were no winter weeds, but a range of summer weeds was present in the Late Harappan deposits (Table S17), though it should be acknowledged that there were only small number of samples from this period. The ecological preferences of the summer weeds in the Late Harappan deposits appear to show some return to the Early Harappan conditions and/or cropping choices, but also some differences (Table S18). Moist soil conditions were common, though drier conditions might be suggested than in the previous two periods, as a greater proportion of dry tolerant or preference weeds were also present and a decreased proportion of flood tolerant species were seen compared with the Mature Harappan period. However, there were still high proportions of summer weed species that were neither tolerant to drought or flood. This pattern could suggest the range of land exploited had increased to include areas that were poorly watered but not drought ridden. It also suggests that water management may not have been carried out as much as in earlier periods. However, this observation should be tempered by the limited number of samples from the Late Harappan period mentioned above. A greater proportion of weeds with sandy soil preference were seen compared with previous periods despite the majority of weeds having no preference for soil texture. This could suggest more leaching potential, but alkali-preference weed proportions increased in this period, and fertility remained moderate. The nitrogen levels again appear to be low because of the presence of only Fabaceae, and the lack of Chenopodiaceae. These levels might suggest that soil disturbance may not have been particularly high (*see* Stevens 1996). While the majority of species were biennial (i.e. can reproduce as annuals or perennials), there was a lack of purely perennial species, as 15% reproduce only through annual cycles, and no species relying on vegetation to continue onto a second year of existence were found. Both the biennial reproduction and reproductive method suggest that there was some slight disturbance of the soil, and the lack of perennials weeds suggests some use of a plough. The Late Harappan weed ecology fits well with the evidence for millets because of their plasticity. The reduced flooding suggested by the weeds would also be good for the growth of the millets as they do not like flooding during early growth, but actually fits well with the ecological preferences of dry farmed rice (Fuller and Qin 2009).

It is difficult to characterise the unusual pattern seen in the Late Harappan period at Masudpur VII, particularly given the low sample size available, but in principle, it is best described as a *sequential multi-cropping* strategy. Winter and summer cereals and pulses were both being grown, alongside perennial fruits. The simultaneous growing of rice, millet, pulses and *Coccinia* cf. *grandis* is an interesting combination. Although the millets may have been grown as maslin crops (*cf*. deWet *et al*. 1983b), *Echinochloa* sp. and rice are likely to have been grown separately, as were *Macrotyloma* cf. *uniflorum*, *Vigna mungo* and *V.acconitifolia*. The *Coccinia* cf. *grandis* will also have needed land to grow prostrate and prevent it from strangling other crops. Such land is commonly found at the side of fields or in marginal spaces near houses, although it can also be gathered as an opportunistic cultivar or even from the wild. The presence of *Coccinia* cf. *grandis* suggests that people may have been trying to use as much of the space as was possible to gain maximal food potential from their land, or that they were expanding the range of food choices to include things previous considered as weeds. The combination of these crops suggests that each of the major summer crop types may have been grown as *mono-crops* in separate parcels of land. The continued use of some sort of ard or plough is possible.

Masupdur I

The site of Masupdur I is a 6-hectare town-sized settlement that is situated 13 km from Rakhigarhi, and was occupied in the Mature Harappan period with some occupation potentially dating immediately before the transition to the post-urban Late Harappan phase (Petrie *et al*. 2009, 2016; Fig.4). A range of cereals, pulses and fruits were attested at Masupdur I, but the archaeobotanical assemblage presents a different picture to that seen at Masudpur VII. Masudpur I had the greatest range of crops seen at all the sites (Table S3; Bates and Petrie in prep). Of these, summer crops formed the largest proportions at 66.12% while winter crops formed only 28.87%, which is in contrast to the proportions seen at Mature Harappan Masudpur VII, situated around five kilometres away. There were very few tree/orchard crops (0.6%) and a small proportion of unknown seasonality crops (4.39%) (Table S19). There appears to have been a focus on barley with a little wheat in the winter season, and in the summer season a mixture of *Echinochloa* sp., *Setaria* sp., and *Panicum* sp. was being grown alongside rice, all in similar proportions. Various pulses (e.g. *Vigna* sp., *Macrotyloma* cf. *uniflorum, Pisum* sp., *Cicer* sp., *Lathyrus* sp., *Lens* cf. *culinaris*), fruits, oilseeds (e.g. *Brassica* sp., *Linum usitatissimum, Sesamum* sp., *Indigofera* sp.) and even a gourd (*Coccinia* cf. *grandis*) were present, but only in small quantities (Table S19).

Unlike Burj and Masudpur VII, winter weeds were attested at Masupdur I, along with summer weeds (Table S20). The ecological preferences of the winter weeds (Table S21) indicates a moist soil preference, though high drought tolerance could suggest reliance on winter rains rather than floodwaters, as there is no evidence or irrigation suggested in the weed ecology. The weeds provide no indication of soil texture, but the alkali preference and the moderate soil fertility suggests leaching was not a problem. The ratio of Fabaceae to Chenopodiaceae weeds is non-season specific, and suggests that soils were slightly more deficient in nitrogen than not (*see* Stevens 1996), which fits the expectation for the area around the site (Table 3). The majority of the weeds were biennial, but reproduction was solely through seed bank, which suggests that there was high soil disturbance, and indicates that plough tillage may have been carried out for winter crops. It is possible that spaces only usable as arable land may have been targeted for winter cropping, but the *Avena* sp. could also have arrived as part of the sowing package as it is the same size as the main winter crop, *Hordeum vulgare*. As such a range of land might have been used. Some of this winter weed ecology fits well with the predominance of *Hordeum vulgare*, which can survive in drought conditions, but prefers not overly dry soils and moderate soil fertility and has no particular soil texture preferences. The high alkali content of the soil is not particularly suited to barley, which generally prefers slightly alkaline to acidic conditions, but given that weeds cannot reliably characterise how alkaline soils are, the high alkali indicators may indeed fit with the barley preferences.

The summer weeds show a different pattern (Table S22), with indications that the soil was dry, with some evidence for drought conditions. The presence of both dry-preference and drought-tolerant weeds indicate poor water management or fit with the distance from the closest river course, though summer flooding from rainfall is likely in this area (Table 3). A slight preference for sandy soils indicated amongst the summer weeds which could suggest some potential for leaching, but the moderate fertility and alkali pH measures, suggested against this and fit with the expected soil types around the site (Table 3), which also indicates that there may not have been extensive soil disturbance (Stevens 1996). The ratio of Fabaceae to Chenopodiaceae weeds is non-season specific, and suggests that soils were generally deficient in nitrogen, which fits the expectation for soils around Masudpur I (Table 3; also see Stevens 1996). Significantly, the majority of weeds are annuals that are reproduced through seed bank. Their presence suggests that heavy soil disturbance may have occurred, and the high proportions of such weeds could potentially indicate plough tillage, which was not seen at the other settlements.

The summer weeds fit well with the main crop choices at Masudpur I, particularly the millets, *Setaria verticillata* and *Echinochloa colona*, and rice, *Oryza* sp. As explored above, millets are a very flexible species in their ecologies and the lack of water management indicated by the weeds fits well with these millet species, as does the moderate soil fertility and the range of soil textures. The rice ecology is, however, particularly interesting in relation to the debates surrounding rice agriculture in the Indus Civilisation (Bates *et al*. 2016a; Petrie *et al*. 2016). The drier summer conditions suggested by the analysis of the weeds at Masudpur I would suggest that the main cropping of *Oryza* sp. at the site was of a native, non-paddy rice species, perhaps a proto-indica (Bates 2016a; Petrie *et al*. 2016; *see* Fuller, 2002, 2006, 2011). *Oryza indica* has many ecological preference similarities to the conditions indicated in the weed ecologies of Masudpur I: i.e. dry-moist soils, but no flood or drought tolerance, a wide range of soil textures, and a lack of preference towards soil pH as the roots are capable of breaking up heavy soils to encourage leaching to remove acids, moderate-low fertility, and a well prepared seed bed, often gained through plough tillage (Table S1).

The proportions of crops attested in the Mature Harappan phase at Masupdur I thus suggest that while there was a *sequential multi-cropping* strategy, dominated by a cereal *duo-culture*, with a likelihood of the *mono-cropping* of wheat and barley in winter, and rice and millet in summer (*see* Galinato *et al*. 1999). Interestingly, the millets might have been grown as a maslin crop, as they are typically recovered together, though this could also reflect taphonomy rather than cropping practices, as it might at all sites. Various pulses, fruits and oilseeds appear in small quantities, suggesting that they played a minimal role in the cropping system, but the presence of *Linum usitatissimum* is notable because it requires well-watered soil, so might only have been *intercropped* with *Triticum* sp. if not grown on separate land. Separate land was likely required to grow *Pisum* sp., and is likely to have been set aside for *V.acconitifolia*, *V.trilobata*, *Coccinia* cf. *grandis* and potentially *Macrotyloma* cf. *uniflorum*, *Vigna radiata* and *Vigna mungo*. In contrast, *Lens* cf. *culinaris, Cicer* sp., and *Lathyrus* sp. could have been intercropped with the winter cereals, or with each other, and *Brassica* sp. and *Sesamum* sp. could have been intercropped with the summer cereals, the latter only with millet. As at

Masudpur VII, the likelihood of some use of a plough is notable, though at Masudpur I, heavier soil disturbance is likely, potentially indicating plough tillage.

Bahola

Bahola is a 1-hectare site that is situated in modern day Karnal district, Haryana and has evidence of Late Harappan and PGW period occupation (Singh *et al*. 2012a, 2013b; Fig.4). The crop assemblages from these phases are dominated by cereals and include both pulses and fruits, but they are distinct from those seen at the other *Land, Water and Settlement* sites, and also from each other (Tables S3, S23).

In the Late Harappan period there was a clear focus on summer cropping, which formed 88.24% of the crop assemblage, which is similar to PGW period Burj and Phase C/D at Rojdi. Only 6.87% of the crop assemblage was identified as winter species, 0.46% were tree/orchard fruit and 4.43% could not be assigned to seasonality. Within the summer portion of the crops, a mix of *Oryza* sp., *Echinochloa* sp. and *Setaria* sp. was commonly observed, and there were also a high proportion of indeterminate small millets (Table S23). *Hordeum vulgare* and indeterminate *Hordeum/Triticum* were the main winter crops, but were relatively minor crops in the overall crop assemblage. Various pulses were present, including *Vigna* sp., *Macrotyloma* cf. *uniflorum*, but no winter pulses were identified, although indeterminate Fabaceae were also noted (Table S23).

Both winter and summer weeds were found in the assemblage from the Late Harappan levels at Bahola (Table S24). The ecological preferences of the winter weed assemblage suggests that although the soils were moist, drought tolerant weeds were the most dominant type, potentially indicating a lack of water management and the potential for very dry situations (Table S25), which fits with the fact that Bahola is isolated from a perennial water source. The weed soil texture preferences do not suggest much about the porosity of the soil nor for the potential for leaching, but do suggest that the soils were generally fertile, and the non-season specific Chenopodiaceae to Fabaceae weed ratios showed high Chenopodiaceae proportions, suggesting good nitrogen levels, and thus potentially manuring. Soil pH can be modified towards acidic levels through manuring and this interpretation is supported by the high acidic preference weed proportion, in an area that is mainly alkali in its soil conditions (Table 3). The two weed species, *Chenopodium* cf. *album* and *Rumex* sp. are also both known to survive in the gut and are commonly found in manure. The high proportion of annuals and seed bank reproducers together with high nitrogen therefore suggest that manuring and plough tillage may have been utilised, and the limited land-types exploited could be indicative of intensive small scale farming.

This contrasts with the ecological preferences of the summer weeds (Table S26), where moist soils, perhaps slightly wetter than those in the winter, and drought tolerant plants dominate, with more flood tolerant species being in evidence. These data could suggest marginally less control over the water/moisture conditions than in the winter seasons, though given the high propensity for fast moving floods in the summer season in the area today it could in fact represent very careful water management to prevent devastation. The high proportion of sandy soil weeds could suggest leaching. This is supported somewhat by the high proportion of acidophiles in an area that is predominantly alkaline (Tables 3 and S26), but looking at the weed soil fertility measures it seems that the soil was moderately fertile, higher than expected for the area, and the high proportion of Chenopodiaceae mentioned above also suggests high nitrogen values. These data suggest that rather than leaching, the high proportion of acidophiles might again be due to manuring. The weed life cycles also differ from the winter season, as the majority of summer weeds are perennials. Although some annuals were present, vegetational spread was the main way of reproducing beyond one year, and there were also a fairly high proportion of seed bank reproducers. This suggests that while there may have been some soil disturbance, it was minimal compared with the winter season. This seems to match the suggestion that the range of land exploited was greater than in the winter season as it encompassed wetlands as well as wastelands, grassland/pastures and arable land.

Interestingly, the weed proportions (Table S24) and weed ecology (Tables S25-26) indicate that the most intensive agriculture was during the winter season, and although it is not visible in the crop assemblage, wheat potentially played a larger role in the winter cropping regime than barley. Barley does not require highly fertile soils nor extremely well-prepared seed beds, whereas wheat has high fertility requirements, is slightly more tolerant of acidic conditions and likes an extremely well-prepared seed bed (Table S1), all of which are suggested by the winter season weeds (Table S25). The main summer crops were *Echinochloa colona*, *Setaria pumila* and *Oryza* sp., which fit well with the Bahola summer weed ecology. These millets are very adaptable, surviving in wetter soils, during dry periods, growing in poor soils and well-fertilised conditions, and also in a range of soil textures and pH. The rice, although preferring moderately fertilised fields, can also survive in highly fertilised fields, and like the millets does not require a well-prepared seed bed as it can break up the soil itself. Similarly, highly acidic conditions are not a problem as the roots can encourage leaching to make conditions more favourable. This all fits with the less intensive soil disturbance noted in the summer weed ecologies.

These Late Harappan crop proportions from Bahola thus indicate the existence of a summer dominated *sequential multi-cropping* strategy that potentially involved *mono-cropping* of rice and a *mixed intercrop* of millets in summer, and *mono-cropping* of barley and indeterminate *Hordeum/Triticum*, perhaps wheat, in winter. The winter oilseed is potentially annual or perennial (*Brassica* sp.) (Tables 1, S24), but could have been grown as a *strip intercrop* with the winter cereals. The summer pulses include both annuals and potential perennials. However, the species that are often grown as *mono-crops* either because of their growth habits (spreading, prostrate or shrubby nature) or because of their labour needs, are likely to have been grown in distinctive plots of land as additional *mono-crops* (e.g. *Vigna radiata* and *Macrotyloma uniflorum*), while others might have been *row* or *strip intercropped* (e.g. *Vigna mungo* and *Vigna trilobata* with millet or each other). Furthermore, the presence of *Coccinia* cf. *grandis* suggests exploitation of field edges for food growth, similar to the pattern seen in the Late Harappan at Masudpur VII, but also at Masudpur I in the Mature Harappan period. The pattern of the low proportions of *Coccinia* cf. *grandis* at sites where it is present potentially indicates that the high proportion of *Coccinia* cf. *grandis* seeds seen at Masudpur VII in the Late Harappan is potentially due to sample size rather than to grand scale changes in dietary or agricultural strategy relating to famine and climate change.

The PGW period at Bahola shows some increase in the proportion of winter crops (17.29%) and a decrease in summer crops (72.88%) (Table S23), perhaps suggesting a more balanced approach to *sequential multi-cropping* was being carried out in this phase. Tree/orchard fruits also increased in proportion to 4.81%, and a small increase in unknown seasonality crops was also seen (5.02% of the crop assemblage) (Table S23). The most commonly occurring crops were again *Oryza* sp., *Echinochloa* sp., and *Setaria* sp. (Table S23), all of which commonly occur together in contexts (Bates 2016: Table 7.11). Indeterminate *Hordeum/Triticum* and *Ziziphus mauritiana* appeared in increased proportions, and although fewer pulse species were attested, the winter crop lentil was found as well as indeterminate Fabaceae, and small quantities of *Indigofera* sp., a dye crop, rather than the food crop of *Coccinia* cf. *grandis* (Table S23).

The PGW period weeds from Bahola were distinct from those recovered from the Late Harappan period contexts (Table S27). *Chenopodium* cf. *album* was present and is the only possible winter season weed, although it does grow across the seasons. The summer weeds suggest the exploitation of a range of soil moistures, though dry and drought tolerant species dominate, suggesting drier rather than wetter conditions (Table S28). These data potentially show similar patterns to the summer weeds of the Late Harappan period at Bahola, suggesting control of water to prevent flooding in the summer months. There is no clear preference for soil texture, though some sand preference was noted. The fertility was moderate, but the nitrogen was low according the non-season specific Fabaceae to Chenopodiaceae weed ratio, and there was also an alkaline preference. All of this is in keeping with the local soil fertility conditions (Table 3). It appears that there was little leaching and also low disturbance of soils, which is supported in the life cycle of the weeds that shows combination of perennial and annual varieties, and seed bank and vegetational reproduction. Taken as a whole, the weed ecology indicates that agricultural practices were less intensive in the PGW period compared with the Late Harappan period.

As in the Late Harappan period, however, the PGW period cropping system was a summer dominated cropping strategy involving *mono-cropping* of rice and a *mixed intercrop* of millets in summer and *mono-cropping* of barley/wheat in winter, combined with the growing of summer pulses and perennial fruit, some of which will have required separate parcels of land, similar to that seen in the Late Harappan period, although *Vigna mungo* and *V.trilobata*, were not present. The winter pulses of lentil could be grown as a *strip intercrop* with the winter cereals. *Indigofera* sp. was present, though its precise growing conditions are difficult to characterise. It can be grown as an *intercrop* (Table S3), although it is not clear which species this might have been with, and as a potential biennial or even perennial it might have required land allocation over multiple years.

VII. Mono-cropping, intercropping and sequential multi-cropping

Archaeobotanical research has developed to the point where a variety of methods can now be used singly or in conjunction to reconstruct the ways in which human populations managed crops (e.g. ethno-archaeology, macro- and microscopic archaeobotanical analysis, weed ecology, and stable isotope analysis). While these approaches lend themselves to research on a range of socio-economic and political themes, we argue that further research along these lines on Indus (and also other assemblages) will benefit from more nuanced interpretation of the evidence provided by the combinations of crop seeds and weeds present in specific context and phases of occupation. This is because different crop and weed seeds have specific ecological requirements, so the presence of specific crops and weeds and the combinations in which the two appear provide insight into their growing conditions and hence the cropping practices that local farmers used in each context to produce them. Ellenberg (1950) and van der Veen (1992) have argued that the type of crop can also influence the associated weed flora because of aspects such as leaf shade and rhythm of growth, so while it is necessary to reconstruct local weed ecologies, considerations of change also need to be incorporated. This observation is relevant to both the Indus context that has been explored here in some detail, but also more broadly. By revisiting an established terminology and ascertaining which crops can be grown together, which crops can grow in a complimentary fashion, and which crops must be kept apart, it is possible to hypothesise about the potential strategies that are likely to have been used to grow particular assemblages of crops. Ascertaining how specific crops were grown in the past and whether they were grown as *mono-crops*, *intercrops* or *sequential multi-crops*, provides clarity and specificity to our understanding of cropping practices, and makes it possible to coherently characterise diversity and variation across both space and time. While such an approach will be informative more broadly when considering issues of adaptation, intensification and resilience, it becomes powerful when used to disaggregate the topic of ‘multi-cropping’, particularly as it has been used in the Indus context.

Environmental variation, and diversity in Indus cropping practices

We have argued here that the level of environmental variation across the zone occupied by Indus populations and the diversity of responses to that variation, mean that nuanced characterisations of cropping strategies are essential for understanding the extent of variation in practice. This is particularly relevant when considering issues of adaptation and intensification (Bates and Petrie in prep), and response and resilience to environmental variation and change (*see* Petrie *et al*. in press/2017). While the term 'multi-cropping' has been has been used for some time in the Indus context, the limited attention to the details of cropping practices has meant that nuanced and interesting variation in the patterns of cropping and 'multi-cropping' strategy choice within and between areas have been masked.

Thus far, Indus 'multi-cropping' has been inferred from archaeological assemblages on the basis of the seasonality of particular crops present in specific samples and/or periods of occupation, and contextual associations, such as crops mixed in storage bins (e.g. Weber 1989, 2003). However, there has been limited consideration of how specific crops were grown, and how combinations of winter and summer crops might have been grown in relation to one another during seasons and across seasons. The approach adopted here has considered a combination of crop and weed ecology and modern ethnographic/agricultural data on intercropping potentials to explore the data from Harappa, Rojdi, Babar Kot and the *Land, Water, Settlement* project and suggests that cropping strategies varied significantly from period to period and sites to site. The degree of variation is highlighted by a correspondence analysis of the presence and absence of specific crop and weed seeds at all of the *Land, Water, Settlement* project sites (Fig.6). This plot shows the clustering of some crop and weed species, and while groups of pulses (e.g. *Pisum*, *Cicer*, *Vigna mungo*) and weeds cluster together, the general pattern is one of variation across both space and time. For example, the presence/absence of crop and weed species and hence the cropping strategies used in the Early, Mature and Late Harappan phase occupations at Masudpur VII are distinct and each phase thus appears in different parts of the plot (see above, also Table 4). The presence/absence of crop and weed species in the Mature Harappan phases at Dabli vas Chugta, Masudpur VII and Masudpur I are similarly distinct and appear in different parts of the plot (see above, also Table 4).

The conclusions presented here are in many ways speculative, as the full range of relevant data is not available from all of the Indus sites for which we have good quality archaeobotanical data, but it nonetheless makes a fundamentally important first step towards a more nuanced and sophisticated understanding of Indus crop management practices. The assessment of the cropping strategies used at the Indus sites that have been discussed here are summarised in Table 4.

Table 4. Summary of the cropping strategies at Indus sites discussed in this paper. The strategies used for the main winter and summer species are differentiated, and then the overall strategies is characterised in terms of the 'dominant' crop/season, and whether additional crops are 'supplementary', 'minor' or 'trace'.

Period	*Region*	*Site*	*Data*	*Cropping strategy*		
				Winter (main species)	*Summer (main species)*	*Overall*
E	W Punjab	Harappa	Crop seeds	*Mono-cropping* of barley and wheat with possible pulse *intercropping*	*Mono-cropping* of millet	Some *sequential multi-cropping* involving (dominant) winter *mono-crops*; (minor) summer *mono-crops*, with potential *intercropping* of pulses and fruits
M	W Punjab	Harappa	Crop seeds	*Mono-cropping* of wheat and barley with possible pulse *intercropping*	*Mono-cropping* of millet with possible *intercropping* or *mono-cropping* of pulses	Some *sequential multi-cropping* involving (dominant) winter *mono-crops*; (minor) summer *mono-crops*, with potential *intercropping* of pulses and fruits, and *mono-crop* of flax
L	W Punjab	Harappa	Crop seeds	*Mono-cropping* of barley and wheat with possible pulse *intercropping*	*Mono-cropping* of millet and rice(?) with possible *intercropping* of pulses	*Sequential multi-cropping* involving (dominant) winter *mono-crops*; (minor/supplementary) summer *mono-crops*, with potential *intercropping* of pulses and fruits, and *mono-crop* of flax
E/A	Gujarat	Rojdi	Crop seeds, weed seeds*	*Mono-cropping* of barley	Possible *intercropping* of *Eleusine* sp. and *Panicum miliare*	Some *sequential multi-cropping* involving (dominant) summer; (trace/ possibly non-local) winter *mono-crop,* with intercropping of fruit (*Ziziphus*)
M/B	Gujarat	Rojdi	Crop seeds, weed seeds*	*Mono-cropping* of Brassica (mustard)	*Mono-cropping* of *Panicum miliare*	Some *sequential multi-cropping* involving (dominant) summer *mono-crops*; (trace/possibly non-local) winter *mono-crop,* with *intercropping* of fruit (*Ziziphus*)
L/C	Gujarat	Rojdi	Crop seeds, weed seeds*	Possible *intercropping* of lentil, *Brassica* (mustard), *Lathyrus* sp. and *Vicia* sp.	*Mono-cropping* of *Setaria* cf. *glauca* and *Setaria italica*	Some *sequential multi-cropping* involving (dominant) summer cereal *mono-crops*; (trace/possibly non-local) winter *intercropping* of cereals and pulses, and *intercropping* of fruit (*Ziziphus*) and pulses
L/C/D	Gujarat	Rojdi	Crop seeds, weed seeds*	Possible *intercropping* of barley, *Lathyrus* sp. and *Vicia* sp.	*Intercropping* of *Eleusine, Panicum miliare* and *Setaria* sp.	Sequential *multi-cropping* involving (dominant) summer *intercropped* cereals; (minor/possibly non-local) winter *intercropped* cereals, fruit (*Ziziphus*) and pulses
IM/I	Gujarat	Babar Kot	Crop seeds, weed seeds*	*Mono-crop* of lentils	*Mono-cropping* of *Panicum miliare*	Very limited *sequential multi-cropping* involving (dominant) summer *mono-crop*; (trace/minor) winter *mono-crop*
L/II	Gujarat	Babar Kot	Crop seeds, weed seeds*	*Mono-crop* or *intercropping* of lentils and *Lathyrus* sp. and *mono-crop* flax	*Mono-cropping* of *Setaria italica* and *Panicum miliare*	Very limited *sequential multi-cropping* involving (dominant) summer *mono-crop*; (trace) winter *mono-crop* or *intercropping*
L/III	Gujarat	Babar Kot	Crop seeds, weed seeds*	*Mono-crop* or *intercropping* of mustard, lentils and *Vicia* sp. and *mono-crop* flax	*Mono-cropping* of *Setaria italica*	Very limited *sequential multi-cropping* involving (dominant) summer *mono-crop*; (trace) winter *mono-crop* or *intercropping* of mustard and pulses, and a *mono-crop* of flax.
M	Rajasthan	Dabli-vas Chugta	Crop seeds, weed seeds	*Mono-cropping* of barley	*Mono-crop* or *mixed intercrops* of millets	Some *sequential multi-cropping* involving (dominant) winter *mono-crops* of barley (and wheat), potentially *intercropped* with pulses/mustard; (supplementary) summer *mono-crop* of millets, *intercropped* with fruit.
E	C Haryana	Burj	Crop seeds, weed seeds	*Mono-cropping* of barley, *intercropping* of Zizyphus		Winter only (dominant) *mono-crop* of barley and possible *intercropping* with fruit.

PGW	C Haryana	Burj	Crop seeds, weed seeds	*Mono-cropping* of barley	*Mixed intercropping* of millets	Some *sequential multi-cropping* involving (dominant) summer millets with *intercropped* tropical pulses, and *strip intercropping* or *mono-cropping* of mung bean; (supplementary/minor) winter *mono-crop* of barley, possibly *intercropped* with winter pulses. Also *mono-cropping* or *strip intercropping* of pea and *intercropping* of fruits.
E	C Haryana	Masudpur VII	Crop seeds, weed seeds	*Mono-cropping* of barley and some wheat	*Intercropping* of millet	*Sequential multi-cropping* involving (dominant) summer *mixed intercroped* millets, possible *intercropping* of pulses and *strip intercropping* or *mono-cropping* of horsegram and *Coccinia grandis*, also *mono-cropping* of rice; (supplementary) winter *mono-crop* of barley and some wheat with possible *intercropping* of pulses and some *strip intercropping* or *mono-cropping* of pea. *Intercropping* of fruit.
M	C Haryana	Masudpur VII	Crop seeds, weed seeds	*Mono-cropping* of wheat and some barley	*Mono-crop* of sawa millet	*Sequential multi-cropping* involving (dominant) winter *mono-crops* of wheat and some barley with possible *intercropping* of pulses and mustard; (supplementary) summer *mono-crop* of sawa millet with possible *intercropping* of pulses and *strip intercropping or mono-cropping* of horsegram and mung bean. *Intercropping* of fruit.
L	C Haryana	Masudpur VII	Crop seeds, weed seeds	*Mono-cropping* of barley	*Mono-crops* of rice and *mixed intercropping* millets	*Sequential multi-cropping* involving (dominant) summer *mono-crops* of rice and some *mixed intercropping* of millets with possible *intercropping* of pulses some *strip intercropping* or *mono-cropping* of horsegram and *Coccinia grandis* in; (supplementary/minor) winter *mono-crop* of barley with possible *intercropping* of pulses and some *strip intercropping or mono-cropping* of pea. *Intercropping* of fruit.
M	C Haryana	Masudpur I	Crop seeds, weed seeds	*Mono-cropping* of barley and some wheat	*mono-crops* of rice and *mixed intercropping* of milllets	*Sequential multi-cropping* involving (dominant) summer *mono-crops* of rice and some *mixed intercropping* of millets with possible *intercropping* of pulses some *strip intercropping* or *mono-cropping* of horsegram, mung bean, sesame, *Indigofera* sp. and *Coccinia grandis*; (supplementary) winter *mono-crop* of barley and some wheat with possible *intercropping* of pulses and mustard and some *strip intercropping* or *mono-cropping* of pea and flax. *Intercropping* of fruit.
L	E Haryana	Bahola	Crop seeds, weed seeds	*Mono-cropping* of barley	*Mono-crops* of rice and *mixed intercropping* of millets	*Sequential multi-cropping* involving (dominant) summer *mono-crops* of rice and separate *mixed intercropping* of millets, possible *intercropping* of pulses and some *strip intercropping* or *mono-cropping* of horsegram, mung bean and *Coccinia grandis*; (supplementary/minor) winter *mono-crop* of barley. *Intercropping* of fruit.
PGW	E Haryana	Bahola	Crop seeds, weed seeds	*Mono-cropping* of barley and wheat	*Mono-crops* of rice and *mixed intercropping* of millets	*Sequential multi-cropping* involving (dominant) summer *mono-crops* of rice and separate *mixed intercropping* of millets, possible *intercropping* of pulses some *strip intercropping* or *mono-cropping* of horsegram, mung bean and *Indigofera* sp.; (supplementary/minor) winter *mono-crop* of barley with possible *intercropping* of pulse and mustard. *Intercropping* of fruit.

* the weed assemblages from Rojdi and Babar Kot have not been analysed in detail here.

Much of the discussion presented here has avoided direct consideration of the dynamics of water supply. In the Indus context, it has been argued that perennial and ephemeral water courses were exploited for flood inundation when present, and when not, the inhabitants relied on rainfall, small-scale irrigation, well/lift irrigation and also ponds to supply water (Miller 2006, 2015; Petrie in press/2017; also Weber 1989: 367-9). There is considerable variation in the distribution of Indus settlements in relation to proximity to these water resources, whether they are produced by rainfall or groundwater. Figure 2 displays the spatial relationship between the known Indus settlements, including the location of the relatively small number of Indus urban centres, and the distribution of winter and summer rainfall. It shows that some Indus settlements are located close to perennial rivers while other were located close to ephemeral water courses, or in areas that so not have any obvious ground water supply (Fig. 2; Petrie *et al*. in press/2017). The locations of the settlements that are suitable for nuanced discussion of cropping strategies are shown in Figure 3. The distribution of these settlements makes it clear that we do not presently have data available that enables a comprehensive discussion of transformations that might have accompanied the shift to urbanism or the range of diversity and variation in Indus cropping practices. This is particularly the case for discussing the potential for variation in cropping practices at the different Indus urban centres, which is certainly likely, but cannot yet be demonstrated. The data from the *Land, Water and Settlement* project sites emphasises the importance of considering smaller village sites, and the potential for considerable variation within regions.

At present we lack high-resolution archaeobotanical information from any of the Indus settlements in Sindh, which is situated along the lower course of the Indus River. The excavations at the urban site of Mohenjo-daro in the early twentieth century only revealed evidence for winter crops, which might suggest that the farmers that provisioned the urban centre practiced single-season winter cropping (Petrie in press/2017; Petrie *et al*. 2016, in press/2017; *see* Weber *et al*. 2010: 72), potentially exploiting inundation flooding caused by summer snow-melt and Indian Summer Monsoon run-off to saturate the soil ready for winter planting (Petrie in press/2017; *see* Miller 2006, 2015). This is, however, largely conjecture, and new excavations and sampling are necessary to ascertain the nature of Indus subsistence and cropping in Sindh, and also the potential transformations that took place in the rise and decline of the urban centre. It is notable, however, that archaeobotanical assemblages from fourth and third millennium BC occupation at Miri Qalat and Sohr Damb, in west and east Baluchistan respectively, demonstrate the predominance of winter crops (Tengberg 1999; Beneke and Neef 2005). It is important, however, to establish whether all of the settlements in Sindh utilised similar approaches to cropping, which can only be demonstrated through systematic archaeobotanical analysis.

The areas of Gujarat, which lie to the east of Sindh, have almost no access to winter rain, and the subsistence strategies attested at the sites of Rojdi and Babar Kot are perhaps logically almost entirely dominated by crops grown in summer, particularly millets (Weber 1989, 1991; Reddy 1994, 2003). The available evidence suggests that farmers practised single-season summer cropping in Gujarat, which is a sharp contrast to the picture that has been hypothesised for Sindh (Petrie in press/2017). Citing the evidence from Rojdi, Weber *et al*. (2010: 73) have indicated that winter crops were also present in Gujarat, but as outlined above, it is more likely that winter crops made a relatively minimal contribution in terms of relative abundance, though this appears to have increased over time. This impression is also matched by the less resolved archaeobotanical evidence from sites including Surkotada (Vishnu Mittre 1990), and Kanmer (Pokharia *et al*. 2011), which both present a wide range of summer crops, though quantification of these assemblages is lacking. We don't as yet have any coherent information about the plant economy and cropping strategies attested at the urban site of Dholavira. Investigations at earlier sites in the region such as Loteshwar have emphasised the importance of interdunal areas for local cropping strategies (García-Granero *et al*. 2016), and it is likely that such contexts continued to be important in the Indus period.

In the areas of greater Punjab that lie to the north of Sindh and Gujarat, the extremes in the availability of water in summer and winter are less pronounced, though there is certainly spatial variation in the quantities of rainfall in either season. Some areas benefit from direct rainfall from both summer and winter rainfall systems, but most areas do not receive direct winter rain, and the quantity of summer rainfall is variable (Fig.2). The geomorphology of the river channels of these northern regions is also likely to have been markedly different to the riverine geomorphology in Sindh (*see* Weber *et al*. 2010: Table 2).

There has been some discussion about the types of cropping that were possible in greater Punjab, with the assumption that summer and winter cropping were both possible and practised (e.g. Weber 1999, 2003; Weber *et al*. 2010). However, the limited amount of well-resolved data from across this region has made holistic discussions problematic, though there has been a tendency to suggest that the plains of northwest India received more summer rain, and thus may have seen more use of summer crops (Fuller and Madella 2002: 354; Madella and Fuller 2006; Fuller and Murphy 2014).

The possibility that there was some variation in practices across greater Punjab intersects with an on-going debate about the date from which Indus populations commonly used winter and summer crops in conjunction (*see* Petrie *et al*. 2016). The observations about cropping practices that have been drawn from the *Land, Water, Settlement* project sites, and also from Harappa, have implications for our understanding of the chronology and spatial resolution of 'multi-cropping' in the Indus context. Previously it has been argued that other than in Gujarat, the exploitation of summer crops was not widespread until the very end of the Indus urban phase, and only became common in the period when the Indus urban system transformed into a rural economy from *c*.1900BC (e.g. Meadow 1996; Fuller and Madella 2002; Fuller 2011; Fuller and Murphy 2014; Pokharia *et al*. 2014). It has long been clear that the archaeobotanical assemblages from Harappa in the western Punjab show the use of summer crops from the earliest phases of occupation (Weber 1999, 2003), though these crops were relatively minor in terms of relative abundance. The archaeobotanical assemblages from the settlements excavated by the *Land, Water, and Settlement* project also clearly indicate that early farmers in eastern Punjab/central Haryana engaged in complex cropping strategies from at least the early third millennium BC. However, it is only from Masudpur VII and Masudpur I that direct radiocarbon dates are now available for several of the winter and summer crops from the same site and contexts (Petrie *et al*. 2016). As shown in Table 4, the data from these two settlements in particular provide explicit evidence for the use of complex and variable *sequential multi-cropping* strategies involving the complex exploitation of winter and summer crops in the periods before, during and after the Indus urban phase (Bates 2016; Bates *et al*. 2016a, 2016b, in press; Petrie *et al*. 2016, in press/2017). The degree of variation across space and over time seen at these two sites is paralleled by the evidence from Dabli vas Chugta, Burj, and Bahola, which are each situated in different parts of this eastern zone. Interestingly both winter and summer weeds indicate that various land types were being exploited at each of these settlements (e.g. arable, wasteland, grassland/pastures, wetland).

Several interesting patterns in the combinations of crops by season are evident at the *Land, Water, Settlement* project sites, which has implications for the practice of *intercropping*. *Echinochloa* sp., *Setaria* sp. and *Panicum* sp. frequently occur together (Table S3), and they may well have been grown as *mixed intercrops* (*see* de Wet *et al*. 1983b). There is, however, little other evidence for *mixed intercropping*, suggesting that particularly for the main crops, the focus was on management of individual crops on distinct parcels of land. The crops that fall into this category include wheat (*Triticum* sp.), barley (*Hordeum vulgare*), pea (*Pisum*), and linseed/flax (*Linum*) in winter, and rice (*Orysa* sp.), sawa millet (*Echinochloa colona*), and mung bean (*Vigna radiata*) and horsegram (*Macrotyloma uniflorum*) in summer. The latter both require the allocation of land either annually or perennially due to growing or management needs There is the possibility of row intercropping of several species, including for example urad bean *(Vigna mungo)* and sesame *(Sesamum* sp.) in some periods/at some sites, though some combinations of crops, like *Vigna mungo* and rice, are not productive and they are likely to have been kept separate (Table S1). The only identifiable fruit in the macrobotanical remains at all sites in all periods was jujube (*Ziziphus mauritiana*), but as there is no evidence for land allocation for long term growth of other more likely orchard fruit trees, *Ziziphus* trees were probably growing on field edges and therefore part of a wide exploitation of natural resources strategy. *Coccinia* cf. *grandis* though often not found in as high proportions, is similarly likely to have been part of this exploitation strategy as it is also often grown round the edges of fields or on marginal land either wild or cultivated for additional vegetable matter.

When taken together, the data from all of the *Land, Water, Settlement* project sites clearly demonstrate that there was variation in the proportions of the crops being exploited across space and over time in northwest India (Table 4; Bates 2016; Petrie *et al*. 2016, in press/2017). When these data are compared with the evidence from Harappa, it appears that the practices in the more easterly regions were distinct from those in western Punjab, at least as represented at Harappa (Table 4). We hypothesise that the areas of greater Punjab can potentially be divided up into at least two and probably more zones where distinct cropping practices were carried out: the first being the western/central Punjab (Fig.5i) – as characterised by Harappa – where a degree of *sequential multi-cropping* was possible, but *mono-cropped* winter cereals predominated; and the second being the area of the eastern Punjab/Haryana (Fig.5ii) and potentially also the zone along the base of the Himalaya (dashed green line), where relatively abundant direct rainfall occurs in both summer and winter. We argue that the climatic and environmental conditions within this latter zone are likely to have made it possible for Indus farmers to grow winter and summer crops in a flexible way, which potentially involved a degree of choice or even innovation in terms of crop selection and specific cropping strategy. It is difficult to be specific about cropping strategies in other areas, because the evidence is simply not available. There has been some discussion about the importance of the Cholistan region as a zone of intensive and extensive cultivation (e.g. Madella 2014), but at present, we have no direct evidence for cropping in this zone (Fig.5, dashed yellow line). It lies at the edge of the alluvial plain on the desert martin, and the only potentially analogous assemblage that has been analysed is that from Dabli-vas Chugta, which is situated in the arid zone of northern Rajasthan at the edge of the Ghaggar palaeochannel (Fig.5). Geomorphological analysis of the area around Dabli-vas Chugta has suggested that it is likely to have benefitted from inundation derived from monsoon-induced inundation during the Early Harappan periods, and presumably later (Singh *et al*. 2012; Neogi 2013; Petrie *et al*. in press/2017).

The proposed zonation of cropping practices across the area occupied by Indus Civilisation populations is similar to, yet fundamentally distinct from, some of the "domains" or "culture-geographic" regions postulated by Possehl (1982, 1992, 1999, 2000) (1982, 1992, 2000) and Joshi (1984; also Weber *et al*. 2010). It also complements Petrie *et al*.'s (in press/2017) suggestion that the variation in practices evident in northwest India indicate that Indus populations in this region engaged in adaptive subsistence strategies that were designed to make use of the prevailing winter and summer rainfall that affects this region, and potentially involved choice and innovation. Further, it supports their suggestion that these adaptive and variable strategies had the potential to be sustainable and resilient, enabling local populations to cope with variable and changing climatic conditions, as the adaptability and flexibility of their practices were well suited to risk mitigation (*see* Petrie in press/2017). When this evidence is taken together with the evidence for winter dominated assemblages involving some summer crops in western Punjab (Fig.5i), the summer dominated assemblages in Gujarat (Fig.5iii), and the hypothetical winter dominated assemblages in Sindh (Fig.5iv), it is likely that there was considerable diversity in cropping practices across the entire Indus zone (*see* Petrie 2013; Petrie *et al*. in press/2017). It is also likely that there was some diversity in terms of the 'multi-cropping' strategies used between each of these cropping regions, and at least *within* the north-eastern area (Petrie *et al*. in press/2017). In particular, we argue that there was considerably more ecological and cultural variation across greater Punjab than has been suggested previously (*see* Petrie *et al*. in press/2017). There is some likelihood that adaptive strategies akin to those hypothesised for northwest India (Petrie *et al*. in press/2017) and western Punjab (Weber 2003; Weber *et al*. 2010) were also ultimately adopted elsewhere within the greater Indus zone, potentially to cope with variable and changing climatic conditions.

Conclusions

It is hoped that the extended discussion of Indus cropping strategies presented here makes an important contribution to our understanding of 'multi-cropping' in the Indus context and also more broadly. In terms of cropping strategies, the Indus Civilisation appears to present multiple trajectories to urbanism, with centres in different areas likely to have been more or less reliant on summer and/or winter crops, and there are undoubted connections to the dynamics of direct and indirect water availability (Petrie in press/2017; Petrie *et al*. in press/2017). Although winter grown wheat and barley were clearly important staple crops in many regions, it has long been clear that summer grown millets were important in others (Weber 1991), and it is now apparent that locally domesticated rice was also being exploited in northwest India (Bates *et al*. 2016a; Petrie *et al*. 2016). All of this diversity was occurring across an area where populations were simultaneously sharing some categories of material culture and maintaining regional diversity in others (e.g. Wright 2010; Petrie *et al*. 2016). The Indus Civilisation thus remains a distinctive and compelling case of early complexity that is worthy of much further study.

The conclusions presented here are not intended to be definitive, but are aimed to open up debate on the topic of 'multi-cropping', ascertain the degree to which 'multi-cropping' can be characterised archaeologically, and encourage further research looking at the range of strategies available to the Indus peoples and beyond. We have certainly not exhausted the range of methods that might be utilised, even with our own data. The final publication of the *Land, Water and Settlement* project excavations will incorporate multi-variate statistical analysis focusing on the relationships between crop and weed species at individual sites, and whether strategies change over time. Future analysis by the ERC funded *TwoRains* project will see more comprehensive statistical analysis combined with the more systematic analysis of new archaeobotanical evidence in conjunction with ethnographic analysis along the lines of that attempted at various sites/locations in the Mediterranean (*see* van der Veen 1992; Halstead 2014), and nuanced isotopic analysis attempted in Europe and the ancient Near East (Bogaard *et al*. 2013, 2015; Fraser *et al*. 2013; Wallace *et al*. 2015; Styring *et al*. 2016). Such multi-method approaches will facilitate more nuanced considerations of cropping strategies, and when they are combined with attention to how those strategies are characterised, there is considerable potential to carry out more focussed studies on a range of issues and themes, particularly of aspects of related to adaptation, intensification and resilience.

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Figure 1. Distribution of Indus Civilisation settlements in relation to the environmental and climatic context of northwest South Asia

Figure 2. Distribution of modern mean a) winter (Jan-Mar), and b) summer (Jun-Aug) rainfall in relation to urban phase settlements. Urban centres are shown as red circles, and other known urban period settlements are shown as orange circles. The light blue line is the 100mm isohyet, and the dark blue line is the 300mm isohyet. Data extracted from Univ. of Delaware monthly global gridded high-res station (land) data set of precipitation from 1900-2008 (v2.01) by D.I. Redhouse.

Figure 3. Comparison of the sowing times, growing periods, water requirements and harvest times of major Indus crops (data primarily obtained from FAO Irrigation and Drainage Paper 24 [1977]: 42-3, Table 22.B; ECOCROP 2016).

Figure 4. Location of Indus settlements discussed in this paper shown as red circles. Other known Indus settlements shown as orange circles.

Figure 5. Hypothetical areas within the Indus zone where distinct cropping strategies were practiced. Hypothetical areas that are at least partially supported by archaeobotanical data are shown with solid lines and shading. Possible areas that lack archaeobotanical data are shown with dashed lines.

Figure 6. Results of the Correspondence Analysis that illustrates the relationship between crops, fruits and weeds as they appear at each of the sites investigated by the *Land, Water and Settlement* project.

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'Multi-cropping', intercropping and adaptation to variable environments in Indus South Asia

SUPPLEMENTARY INFORMATION (SI)

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SI.1. Ecological requirements of crop and weed species

Table S1. Ecological requirements of major crop species (data obtained from ECOCROP 2016 [find form] website, accessed 15/02/2016)

Crop	***Season***	***A/P***	***Growth***	***Water***	***Rainfall Optimal range (min-max)***	***Salinity***	***Soil***	***Soil depth***	***Fertility***	***pH Optimal range (min-max)***	***Management***	***Companion Crops***	***Cycle***	***Additional***
Triticum cf. *aestivum/durum*	R	A	Erect, bright light	Well drained with dry spells but not drought tolerant, requires higher rainfall than other winter cereals.	750-900 (300-1600) 500-700 (400-800)	Low to medium tolerance (<4 dS/m to 4-10 dS/m)	Medium to heavy to medium texture	Medium (50-150cm) to shallow (20-50cm)	High to moderate	6-7 (5.5-8.5)	Permanent rain fed mono-cropping Permanent rain fed ley cropping[1] with high mechanization but low labour intensity		90-250 days 120-180 days	
Hordeum vulgare	R	A	Erect, bright light, freely tillering	Well drained with dry spells, tolerant drought and of 'dry conditions' due to its precocity (Harlan and Martini 1936). However, does not do well in excessive moisture.	500-1000 (200-2000)	Low to high tolerance (<4 dS/m to >10 dS/m)	Medium to any soil texture	Deep (>>150cm) to medium (50-150cm)	Moderate to low	6.5-7.5 (6-8)	Permanent rain fed ley cropping with high mechanization and low intensity	None but suitable for rotation with legumes and pasture	90-240 days	
Oryza sp. (indica used)	K	A	Erect, very bright	Poorly drained, saturated for >50% of year	1500-2000 (1000-4000)	Low (<4 dS/m)	Any texture; Wide texture generally but dependant on species and management system	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5-8 (3.5-9)	Range of management systems dependant on rice species and watering system (see Fuller *et al.* 2011: Fig. 1; Weisskopf *et al.* 2014: Fig. 1)		80-200 days	Cannot be grown with *Echinochloa colona* as this is a competitive species (Galinato et al., 1999)
Echinochloa colona	K	A	Erect but tillering multi-stem and spreads (Galinato et al., 1999), very bright to light shade	Poorly drained, saturated for >50% of the year to well drained with dry spells	500-1200 (400-2000)	Low to medium tolerance (<4 dS/m to 4-10 dS/m)	Heavy to medium texture	Shallow (20-50cm)	Moderate	5.5-6.5 (5-7)		Can be grown as maslin with various *Setaria* sp. and *Panicum* sp. (de Wet et al., 1983a)	45-180 days	Cannot be grown with *Oryza* sp. as this is a competitive species (Galinato et al., 1999).

[1] Ley cropping – rotation of crops with pulses and/or pasture.

Crop	*Season*	*A/P*	*Growth*	*Water*	*Rainfall Optimal range (min-max)*	*Salinity*	*Soil*	*Soil depth*	*Fertility*	*pH Optimal range (min-max)*	*Management*	*Companion Crops*	*Cycle*	*Additional*
Setaria pumila	K	A	Erect, very bright	From excessively dry to poorly drained, saturated for >50% of year, both drought and flood tolerant	350-500 (150-1200)	Low (<4 dS/m)	Medium to light to any soil texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5.5-6.2 (5-7)		Can be grown as maslin with various *Setaria* sp. and *Panicum* sp. (de Wet et al., 1983a)	75-150 days	
Panicum sp. (potentially P. sumatrense)	K	A	Erect, very bright	From excessively dry to poorly drained, saturated for >50% of year, both drought and flood tolerant	350-500 (150-1200)	Low (<4 dS/m)	Medium to light to any soil texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5.5-6.2 (5-7)		Can be grown as maslin with various *Setaria* sp. and *Panicum* sp. (de Wet et al., 1983a)	75-150 days	
Vigna radiata	K	A/P	Climber/prostrate, very bright, vine/sub-shrub	Excessively dry to well drained with dry spells, drought resistant, not tolerant to waterlogging	650-900 (500-1250)	Low to medium tolerance (<4 dS/m to 4-10 dS/m)	Medium to any soil texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5.5-6.2 (4.3-8.3)			50-120 days	
Vigna mungo	K	A	Semi-erect/prostrate/procumbent , very bright	Excessively dry to well drained with dry spells, best grown during dry weather with residual soil moisture, drought tolerant	650-900 (530-2430)	Low to medium tolerance (<4 dS/m to 4-10 dS/m)	Heavy/ medium texture	Deep (>> 150cm) to medium 50-150cm)	High to moderate	5.5-6.5 (4.5-7.5)			60-130 days	
Vigna aconitifolia	K	A/P	Semi-erect/prostrate/procumbent, very bright	Excessively dry to well drained with dry spells, intolerant to floods	500-900 (400-2500)	Low (<4 dS/m)	Light to any texture	Medium (50-150cm) to shallow (20-50cm)	Low	6.5-7.5 (5-8)	Low management in permanent rain fed systems	Millet and cotton inter-cropping	60-90 days	
Vigna trilobata	K	A/P	Semi-erect/prostrate/procumbent	Well drained with dry spells to poorly drained (including saturated soils for up to 50% of year)	700-900 (520-1440)	Low to medium tolerance (<4 dS/m to 4-10 dS/m)	Heavy/medium to any texture	shallow (20-50cm)	Moderate to low	7-8.5 (6.5-9)	Low management (small scale, manual) in grazing system with 'phase planting'	*Panicum coloratum, P. maximum, Setaria incrassate, Clitoria ternatea, Desmanthus* sp. *Stylosanthes seabrana*	30-60 days	Grazing and browsing tolerance, yields of 3 tonnes/ha/yr possible but may be considerably less, can be eaten as veggie but mostly a green manure

Crop	*Season*	*A/P*	*Growth*	*Water*	*Rainfall Optimal range (min-max)*	*Salinity*	*Soil*	*Soil depth*	*Fertility*	*pH Optimal range (min-max)*	*Management*	*Companion Crops*	*Cycle*	*Additional*
Macrotyloma uniflorum	K	A	Prostrate/procumbent/semi-erect/climber/scrambler/scadent, very light	Well drained with dry spells to excessively dry, drought tolerance, not flood tolerant	500-1200 (300-4300)	Low to medium tolerance (<4 dS/m to 4-10 dS/m	Medium/light to any texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5.5-7 (5-8)	Low to medium depending on system ((if permanent rain fed intercropping or ratoon = medium)	Permenant rain fed intercropping with sorghum, maize, niger seed, cotton, *Eleusine*, lentils; permanent rai nfed ratoon with rice, sesame; grazing with *Heteropogon contortus*, *Panicum maximum, Macroptilium atropurpureum*, *Stylosanthes scabra*; can also be permanent rain fed mono cropping; also arable irrigated mono cropping	40-180 days	Yields in India vary between 200-900kg/ha
*Pisum (*potentially *sativum*)	R	A	Prostrate/procumbent/semi-erect/climber/scrambler/scadent, very light	Well drained with dry spells	800-1200 (350-2500)	Low (<4 dS/m)	Any texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5.5 -7 (4.5-8.3)		Arable irrigated ley cropping (rotating crops with legumes and grass pasture)	60-140 days	
Cicer (potentially *arietinum*)	R	A	Erect, very light	Well drained with dry spells to excessively dry	600-1000 (300-1800)	Low to medium tolerance (<4 dS/m to 4-10 dS/m	Heavy/ medium to any texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	6-8.5 (4.7-9.5)		Arable irrigated ratoon with pearl millet, sorghum, maize, cotton, guar, sesame, rice, jute, durum wheat, wheat, barley, linseed, rapeseed, safflower, tef, faba bean, berseem; arable irrigated intercropping with safflower, sorghum, maize	90-180 days	
Lens culinaris	R	A	Erect, very light	Well drained with dry spells to excessively dry	600-1000 (250-2500)	Low to medium tolerance (<4 dS/m to 4-10 dS/m	Heavy/medium to any texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5.5-7.5 (4.5-8.2)			70-240 days	
Lathyrus (potentially *sativus*)	R	A	Erect, very light	Well drained with dry spells but also from poorly drained (including saturated for up to 50% of year) to excessively dry	500-1300 (320-3000)	Low (<4 dS/m)	Any texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	6-7.5 (4.5-8.3)			100-190 days	If eaten together with *V. sativa* can have paralytic effects!!!)
*Vicia (*potentially *ervilia)*	R	A	Erect/climber or scrambler/scandent, multi-stem	Well drained with dry spells, drought tolerant	500-700 (300-1200)	Low (<4 dS/m)	Any texture	Medium (50-150cm) to shallow (20-50cm)	High to moderate	7-7.5 (5.6-8.2)			90-150 days	

Crop	*Season*	*A/P*	*Growth*	*Water*	*Rainfall Optimal range (min-max)*	*Salinity*	*Soil*	*Soil depth*	*Fertility*	*pH Optimal range (min-max)*	*Management*	*Companion Crops*	*Cycle*	*Additional*
Ziziphus mauritiana	N/A	P	Erect, very light	Well drained with dry spells but also from poorly drained (including saturated for up to 50% of year) to excessively dry, drought tolerant	300-1500 (130-4000)	Low to medium tolerance (<4 dS/m to 4-10 dS/m Salt sensitive!!!! (better to exploit *Z. nummularia*)	Medium/light, to wide texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	5.5-7.5 (5-8.5)				Takes 6-8 years to start to bear fruit; yield increases after 15-20 years
*Brassica (*potentially *nigra)*	R	A/P	Erect	Well drained with dry spells	600-1400 (300-2500)	Low (<4 dS/m)	Medium to any texture	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	6 to 7 (5.3 to 7.8)			120-180 days	Dry season after emergence of fruit will hamper development of seeds, causing severe loss of yield
Indigofera (tinctoria used *because most greedy)*	K	A/B/P	Erect, very light	Well drained with dry spell	1300-1700 (640-3000)	Low (<4 dS/m)	Medium to medium and light	Medium (50-150cm) to shallow (20-50cm)	Moderate to low	6 to 7 (4.3 to 8.7)	Arable irrigated intercropping		90-120 days	Grown on a small scale
*Sesamum (*potentially *indicum*)	K	A	Erect, very light	Well drained with dry spells to excessively dry	500-1000 (300-1500)	Low (<4 dS/m)	Medium to any texture	Deep (>>150cm) to medium (50-150cm)	Moderate to low	5.5-7.5 (4.5-8)	Low (ley cropping but also high mechanization) to medium (intercropping)	permanent rainfed intercropping with sorghum, millet, maize, pigeon peas, finger millet		
Linum usitatissimum	R	A/B/P	Erect, cloudy skies	Well drained with dry spells	500-800 (250-1300)	Low (<4 dS/m)	Heavy/medium	Shallow (20-50cm)	High	6-6.5 (5.5-7)			80-180 days	

Table S2. Ecological requirements of weed species (after Bates 2016: Table VI.1-13)

S2.i: Details by species for water preferences of weeds

Species	Wet	Dry	Wet/dry	References
Chenopodium album			X	Holm et al. (1977); Sen (1981) prefer wetter but can grow in dry; Saraswat (1993);
Fumaria sp.			X	eFlora (2016) [Fumaria] 'moist'; Murrumbidgee (2016) [Fumitory];Anbg (2016) [Fumaria] does not like flooding;
Trianthema triquetra/ portulacastrum	X			Galinato *et al*. (1999)
Solanum dulcamara	X			Fed (2016) [Solanum]
Coix lacrym-jobi	X			Proseanet (2016) [Coix]; Pfaf (2016) [Coix]
Chrysopogon cf. *aciculatus*			X	FAO (2016) [Chrysopogon] moist but well drained
Echinochloa crus-galli			X	Caton et al. (2010); Galinato *et al*. (1999); Holm et al. (1977); Saraswat (1993); Sen (1981) wet/dry, but more often wet; Hooker (1875) wet
Papaver cf. *rhoeas*			X	Pfaf (2016) [Papaver] 'moist'
Pennisetum glaucum		X		FAO (2016) [Pennisetum]; ECOCROP (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used	X			ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used			X	Idao (2016) [Brachiaria]; Icunredlist (2016) [Brachiaria]; ECOCROP (2016) [Brachiaria]
Wild *Hordeum* (*murinum*)			X	Johnston et al. (2009)
Aeluropus sp. *lagopoides* used			X	Arkive (2016) [Aeluropus]; Tropicos (2016) [Aeluropus]
Eragrostis sp.		X		Tropicos (2016) [Eragrostis]; ECOCROP (2016) [Eragrostis]
Medicago/Melilotus/Trifolium			X	Pfaf (2016) [Medicago]; Ucanr (2016) [Medicago]
Stellaria sp.			X	Fascicles of the Flora of India; Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]
Eleocharis sp.	X			Tropicos (2016) [Eleocharis]; Pfaf (2016) [Eleocharis]
Scirpus sp.	X			Tropicos (2016) [Scirpus]
Avena sp.		X		ECOCROP (2016) [Avena] – well drained
Polygonaceae			X	Tropicos (2016) [Polygonaceae]
Cyperaceae			X	Saraswat (1993)
Fabaceae			X	Tropicos (2016) [Fabaceae]
Rumex sp.	X			Tropicos (2016) [Rumex]

Table S2.ii. Details by species for soil fertility preferences of weeds

	Fertile	Interm.	Infertile	References
Chenopodium album	X			Holm et al. (1977); Sen (1981); Weedecology (2016) [Chenopodium]
Fumaria sp.			X	ECOFLORA (2016) [Fumaria]
Trianthema triquetra/		X		Galinato *et al*. (1999); Tanveer et al. (2013); Tropicos (2016) [Trianthema] likes saline soil

portulacastrum				
Solanum dulcamara	X			Fed (2016) [Solanum]
Coix lacrym-jobi	X			Proseanet (2016) [Coix]; Prota (2016) [Coix]; FAO (2016) [Coix]
Chrysopogon cf. *aciculatus*		X		ECOCROP (2016) [Chrysopogon]
Echinochloa crus-galli	X			Caton et al. (2010); Galinato et al. (1999); Holm et al. (1977); Sen (1981); Hooker (1875); ECOCROP (2016) [Echinochloa]; Tropicos (2016) [Echinochloa]
Papaver cf. *rhoeas*	X			Homeguides (2016) [Papaver]
Pennisetum glaucum		X		FAO (2016) [Pennisetum] well drained; ECOCROP (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used	X			ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used		X		ECOCROP (2016) [Brachiaria]; Tropicos (2016) [Brachiaria]
Wild *Hordeum* (*murinum*)	X			Archive (2016) [Hordeum]
Aeluropus sp. *lagopoides* used			X	Arkive (2016) [Aeluropus]; Tropicos (2016) [Aeluropus]
Eragrostis sp.		X		USDA (2016) [Eragrostis]
Medicago/Melilotus/ Trifolium	X	X		Pfaf (2016) [Medicago]; Ucanr (2016) [Medicago]; nitrogen fixers
Stellaria sp.		X		Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]; likes fertile soils but not necessary
Eleocharis sp.		X		USDA (2016) [Eleocharis]
Scirpus sp.		X		Tropicos (2016) [Scirpus]
Avena sp.		X		ECOCROP (2016) [Avena] – well drained; Sen (1981)
Polygonaceae		X		Tropicos (2016) [Polygonaceae]
Cyperaceae		X		Tropicos (2016) [Cyperaceae]
Fabaceae		X		Tropicos (2016) [Fabaceae]; nitrogen fixers
Rumex sp.		X		Stevens (1996)

Table S2.iii. Details by species for soil texture preferences of weeds

	Heavy/ Clay	Loam	Light/ Sandy	References
Chenopodium album	X	X	X	Holm et al. (1977); Hooker (1875)
Fumaria sp.				No information available
Trianthema triquetra/ portulacastrum			X	Plantnet (2016) [Trianthema]
Solanum dulcamara	X	X	X	Fed (2016) [Solanum]
Coix lacrym-jobi	X	X	X	Pfaf (2016) [Coix]
Chrysopogon cf. *aciculatus*			X	Caton et al. (2010); Galinato et al. (1999); ECOCROP (2016) [Chrysopogon]
Echinochloa crus-galli		X	X	Caton et al. (2010); Galinato et al. (1999
Papaver cf. *rhoeas*		X	X	RHS (2016) [Papaver]
Pennisetum glaucum			X	Galinato et al. (1999); ECOCROP (2016) [Pennisetum]

Paspalum sp. – *scrobiculatum* used	X	X	X	ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used			X	Galinato et al. (1999); ECOCROP (2016) [Brachiaria]
Wild *Hordeum* (*murinum*)	X			Archive (2016) [Hordeum]
Aeluropus sp. *lagopoides* used			X	Tropicos (2016) [Aeluropus]
Eragrostis sp.	X	X	X	ECOCROP (2016) [Eragrostis]
Medicago/Melilotus/Trifolium	X	X	X	Pfaf (2016) [Medicago]; Ucanr (2016) [Medicago]
Stellaria sp.	X	X	X	Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]
Eleocharis sp.	X	X	X	Pfaf (2016) [Eleocharis]
Scirpus sp.	X	X	X	Tropicos (2016) [Scirpus]
Avena sp.	X	X	X	ECOCROP (2016) [Avena]
Polygonaceae	X	X	X	Tropicos (2016) [Polygonaceae]
Cyperaceae	X	X	X	Tropicos (2016) [Cyperaceae]
Fabaceae	X	X	X	Tropicos (2016) [Fabaceae]
Rumex sp.	X			Tropicos (2016) [Rumex]

Table S2.iv. Details by species for soil pH preferences of weeds

	Alkaline (9-15)	Near neutral (6-8)	Acid (1-5)	References
Chenopodium album	X	X	X	Holm et al. (1977); Hooker (1875)
Fumaria sp.	X	X		Murrumbidgee (2016) [Fumitory_revised]; ECOFLORA (2016) [Fumaria]
Trianthema triquetra/ portulacastrum	X	X		Tanveer et al. (2013)
Solanum dulcamara	X	X	X	Fed (2016) [Solanum]
Coix lacrym-jobi		X	X	Pfaf (2016) [Coix]
Chrysopogon cf. *aciculatus*			X	Galinato et al. (1999); ECOCROP (2016) [Chrysopogon]
Echinochloa crus-galli		X		ECOCROP (2016) [Echinochloa]
Papaver cf. *rhoeas*	X	X	X	RHS (2016) [Papaver]
Pennisetum glaucum		X	X	FAO (2016) [Pennisetum]; ECOCROP (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used			X	ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used		X		Miles et al. (1996); ECOCROP (2016) [Brachiaria] can tolerate slightly towards the acidic
Wild *Hordeum* (*murinum*)				No information available
Aeluropus sp. *lagopoides* used	X			Tropicos (2016) [Aeluropus]
Eragrostis sp.		X	X	ECOCROP (2016) [Eragrostis]

Medicago/Melilotus/Trifolium	X	X		Pfaf (2016) [Medicago]; Ucanr (2016) [Medicago]; not acidic
Stellaria sp.	X	X		Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]
Eleocharis sp.		X		Pfaf (2016) [Eleocharis];
Scirpus sp.	X	X	X	Tropicos (2016) [Scirpus]
Avena sp.		X	X	ECOCROP (2016) [Avena]
Polygonaceae	X	X	X	Tropicos (2016) [Polygonaceae]
Cyperaceae	X	X	X	Tropicos (2016) [Cyperaceae]
Fabaceae	X	X	X	Tropicos (2016) [Fabaceae]
Rumex sp.			X	Tropicos (2016) [Rumex]

Table S2.v. Details by species for flood preferences of weeds

	Flood	Neither	Drought	References
Chenopodium album			X	Weedecology (2016) [Chenopodium]
Fumaria sp.			X	Murrumbidgee (2016) [Fumitory_revised]
Trianthema triquetra/ portulacastrum		X		Galinato et al. (1999)
Solanum dulcamara				No information available
Coix lacrym-jobi	X			FAO (2016) [Coix]
Chrysopogon cf. *aciculatus*			X	ECOCROP (2016) [Chrysopogon]; JStor (2016) [Chrysopogon]
Echinochloa crus-galli	X			Galinato et al. (1999); ECOCROP (2016) [Echinochloa], can tolerate acidic
Papaver cf. *rhoeas*		X		Homeguides (2016) [Papaver]
Pennisetum glaucum			X	FAO (2016) [Pennisetum]; ECOCROP (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used	X			ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used			X	Galinato et al. (1999); ECOCROP (2016) [Brachiaria]
Wild *Hordeum* (*murinum*)				No information available
Aeluropus sp. *lagopoides* used			X	Tropicos (2016) [Aeluropus]
Eragrostis sp.		X		ECOCROP (2016) [Eragrostis]
Medicago/Melilotus/Trifolium			X	Ucanr (2016) [Medicago]; not flood
Stellaria sp.		X		Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]
Eleocharis sp.	X			Pfaf (2016) [Eleocharis]
Scirpus sp.	X	X	X	Tropicos (2016) [Scirpus]
Avena sp.				ECOCROP (2016) [Avena]– well drained
Polygonaceae	X	X	X	Tropicos (2016) [Polygonaceae]
Cyperaceae	X	X	X	Tropicos (2016) [Cyperaceae]
Fabaceae	X	X	X	Tropicos (2016) [Fabaceae]
Rumex sp.	X	X	X	Tropicos (2016) [Rumex]

Table S2.vi. Details by species for reproductive cycle of weeds

	Perennial	Biennial	Annual	References
Chenopodium album			Arable, grassland, pasture, wasteland	Holm et al. (1977); Sen (1981); Hooker (1875); Tropicos (2016) [Chenopodium]
Fumaria sp.			Arable, wasteland	Hooker (1875); Tropicos (2016) [Fumaria]; Murrumbidgee (2016) [Fumitory_revised]
Trianthema triquetra/ portulacastrum			Arable, pasture, wasteland	Galinato et al. (1999); Hooker (1875); Tropicos (2016) [Trianthema]
Solanum dulcamara	Wetland, grassland, woodland			Fed (2016) [Solanum]
Coix lacrym-jobi	Arable, grassland, wetland		Arable, wetland	Hooker (1875); FAO (2016) [Coix]; Proseanet (2016) [Coix]
Chrysopogon cf. *aciculatus*	Arable, pasture, grassland, wasteland			Caton et al. (2010); Galinato et al. (1999); Hooker (1875); ECOCROP (2016) [Chrysopogon]; Indiabiodiversity (2016) [Chrysopogon]
Echinochloa crus-galli			Arable, wetland, grassland	Caton et al. (2010); Galinato et al. (1999);
Papaver cf. *rhoeas*			Arable, grassland, pasture, wasteland	Hooker (1875); Kew (2016) [Papaver]
Pennisetum glaucum			Arable, grassland, pasture, wasteland	Galinato et al. (1999); Hooker (1875);
Paspalum sp. – *scrobiculatum* used	Arable, pasture		Arable, pasture	Hooker (1875); ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used			Arable, pasture, grassland, wasteland	Galinato et al. (1999); Hooker (1875); ECOCROP (2016) [Brachiaria]; Tropicos (2016) [Brachiaria]; undisturbed land preferred
Wild *Hordeum* (*murinum*)			Arable, grassland	Hooker (1875); Tropicos (2016) [Hordeum]
Aeluropus sp. *lagopoides* used	Arable, wasteland			Tropicos (2016) [Aeluropus]; Kew (2016) [Aeluropus]
Eragrostis sp.			Arable, wasteland	Hooker (1875); Tropicos (2016) [Eragrostis]; ECOCROP (2016) [Eragrostis]
Medicago/Melilotus/Trifolium	Arable, pasture, wasteland	Arable, pasture, wasteland	Arable, pasture, wasteland	Hooker (1875); Ucanr (2016) [Medicago]; not flood
Stellaria sp.	Grassland, pasture		Grassland, pasture	Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]
Eleocharis sp.	Wetland		Wetland	Hooker (1875); Pfaf (2016) [Eleocharis]
Scirpus sp.				Hooker (1875); Tropicos (2016) [Scirpus] wetland
Avena sp.	Arable		Arable	Holm et al. (1977); Sen (1981); Hooker (1875); ECOCROP (2016) [Avena] – well drained
Polygonaceae	Various	Various	Various	Tropicos (2016) [Polygonaceae]
Cyperaceae	Various	Various	Various	Tropicos (2016) [Cyperaceae]
Fabaceae	Various	Various	Various	Tropicos (2016) [Fabaceae]

Rumex sp.	Arable, grassland	Holm et al. (1977); Hooker (1875); Tropicos (2016) [Rumex]

Table S2vii. Details by species for seasonality of weeds

	Rabi	*Kharif*	Other	References
Chenopodium album			X (Jan.-Sept.)	Hooker (1875); Tropicos (2016) [Chenopodium]
Fumaria sp.	X	X		Hooker (1875) Dec.-March; Tropicos (2016) [Fumaria] March-June; FlowersofIndia (2016) [Fumaria] April-May; eFlora (2016) [Fumaria] late winter
Trianthema triquetra/ portulacastrum		X		Hooker (1875); Tropicos (2016) [Trianthema]
Solanum dulcamara		X		Hooker (1875); Tropicos (2016) [Solanum]
Coix lacrym-jobi		X		Hooker (1875); FAO (2016) [Coix]; Proseanet (2016) [Coix]
Chrysopogon cf. *aciculatus*		X		Indiabiodiversity (2016) [Chrysopogon]
Echinochloa crus-galli		X		Saraswat (1993)
Papaver cf. *rhoeas*		X		Hooker (1875)
Pennisetum glaucum		X		FAO (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used		X		Hooker (1875); ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used		X		Saraswat (1993)
Wild *Hordeum* (*murinum*)	X			Hooker (1875); Tropicos (2016) [Hordeum]
Aeluropus sp. *lagopoides* used		X		Tropicos (2016) [Aeluropus]
Eragrostis sp.		X		Tropicos (2016) [Eragrostis]
Medicago/Melilot us/Trifolium	X			Hooker (1875); Ucanr (2016) [Medicago]; Agriculture-Aajtak (2016) [Medicago]; Irrd (2016) [Medicago]
Stellaria sp.		X		Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]
Eleocharis sp.		X		Hooker (1875); Pfaf (2016) [Eleocharis]
Scirpus sp.				No information available
Avena sp.	X			Sen (1981); Saraswat (1993);
Polygonaceae				Various
Cyperaceae				Various
Fabaceae				Various
Rumex sp.	X			Holm et al. (1977); Hooker (1875); Tropicos (2016) [Rumex]

Table S2.viii. Details by species for natural habitat of weeds

	Natural habitat	References
Chenopodium album	Fields, gardens, ruderal, roadsides, irrigated land, slopes	Hooker (1875); Tropicos (2016) [Chenopodium]; Weedecology (2016) [Chenopodium]

Fumaria sp.	Wasteland, field borders	Hooker (1875); Tropicos (2016) [Fumaria]
Trianthema triquetra/ portulacastrum	Disturbed land, rocky, hillsides, cultivated areas, wasteland	Hooker (1875); Shetty & Singh (1987); Gonçalves (1978); Tropicos (2016) [Trianthema]; Indiabiodiversity (2016) [Trianthema]
Solanum dulcamara		No information available
Coix lacrym-jobi	Marshy land	Hooker (1875); FAO (2016) [Coix]; Proseanet (2016) [Coix]
Chrysopogon cf. *aciculatus*	Abandoned cultivated soil, dry deciduous forests, plains	Indiabiodiversity (2016) [Chrysopogon]
Echinochloa crus-galli	Swampy areas, ponds	Galinato et al. (1999); ECOCROP (2016) [Echinochloa]
Papaver cf. *rhoeas*	Arable fields, disturbed land	Wildseed (2016) [Papaver]
Pennisetum glaucum	Waste places, stubble fields, pastures, meadows	Galinato et al. (1999)
Paspalum sp. – *scrobiculatum* used	Arable weed, pasture, watery places, swampy places,	ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used	Wasteland, undisturbed places, pastures, ditches, cultivated land	Galinato et al. (1999); ECOCROP (2016) [Brachiaria]; Tropicos (2016) [Brachiaria]; undisturbed land preferred
Wild *Hordeum* (*murinum*)	Cultivated land only (introduced to region)	Hooker (1875); Tropicos (2016) [Hordeum]
Aeluropus sp. *lagopoides* used	Salt marshes, wasteland, abandoned cultivated land	Tropicos (2016) [Aeluropus]
Eragrostis sp.	Wasteland, abandoned cultivated land	Tropicos (2016) [Eragrostis]
Medicago/Melilotus/Trifolium	Fields, cultivated land, wasteland, disturbed area	Hooker (1875); Ucanr (2016) [Medicago]; Agriculture-Aajtak (2016) [Medicago]; Irrd (2016) [Medicago]
Stellaria sp.	Disturbed land	Pfaf (2016) [Stellaria]; Ucipm (2016) [Stellaria]
Eleocharis sp.	Wetlands, marshes, ponds	Pfaf (2016) [Eleocharis]
Scirpus sp.		No information available
Avena sp.	Cultivated land only (introduced to region)	Sen (1981); Saraswat (1993);
Polygonaceae		Various
Cyperaceae		Various
Fabaceae		Various
Rumex sp.		No information available

Table S2.ix. Details by species for photosynthetic pathways of weeds

	C3	C4	References
Chenopodium album	X		Weedecology (2016) [Chenopodium]
Fumaria sp.	X		ECOFLORA (2016) [Fumaria]
Trianthema triquetra/ portulacastrum		X	Sikolia et al. (2009)
Solanum dulcamara			No information available
Coix lacrym-jobi		X	Proseanet (2016) [Coix]

Chrysopogon cf. *aciculatus*		X	Rundell (1980)
Echinochloa crus-galli		X	Galinato et al. (1999)
Papaver cf. *rhoeas*	X		Garćia-Palacios et al. (2011)
Pennisetum glaucum		X	Galinato et al. (1999); FAO (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used		X	ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used		X	ECOCROP (2016) [Brachiaria]
Wild *Hordeum* (*murinum*)	X		
Aeluropus sp. *lagopoides* used		X	Waghmode (1979)
Eragrostis sp.		X	Waller & Lewis (1979)
Medicago/Melilotus/Trifolium	X		Garćia-Palacios et al. (2011); Boutton et al. (1980); Kimble et al. (2000)
Stellaria sp.	X		Pfaf (2016) [Stellaria]
Eleocharis sp.	X		Bruhl & Wilson (2007)
Scirpus sp.			No information available
Avena sp.	X		
Polygonaceae			No information available
Cyperaceae	X	X	Bruhl & Wilson (2007)
Fabaceae			No information available
Rumex sp.			No information available

Table S2.x. Details by species for reproductive method of weeds

	Seed bank	Vegetational spread	Both	References
Chenopodium album	X			Weedecology (2016) [Chenopodium]
Fumaria sp.	X			Murrumbidgee (2016) [Fumitory_revised]
Trianthema triquetra/ portulacastrum			X	Tanveer et al. (2013); Galinato et al. (1999); Tropicos (2016) [Trianthema]; Plantnet (2016) [Trianthema]
Solanum dulcamara				No information available
Coix lacrym-jobi		X		Proseanet (2016) [Coix]; FAO (2016) [Chrysopogon]
Chrysopogon cf. *aciculatus*		X		ECOCROP (2016) [Chrysopogon]
Echinochloa crus-galli			X	Galinato et al. (1999)
Papaver cf. *rhoeas*	X			Kew (2016) [Papaver]
Pennisetum glaucum		X		FAO (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used		X		ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used			X	Bhatt & Singh (2007)

Wild *Hordeum* (*murinum*)				Neither: seed only, little evidence for seed dormancy Archive (2016) [Hordeum]; Wric (2016) [Hordeum]
Aeluropus sp. *lagopoides* used		X		Gulzar & Khan (2001); Tropicos (2016) [Aeluropus]; Kew (2016) [Aeluropus]
Eragrostis sp.	X			Tropicos (2016) [Eragrostis]
Medicago/Melilotus/Trifolium	X			Fed (2016) [Melilotus]
Stellaria sp.			X	Ucipm (2016) [Stellaria]; Pfaf (2016) [Stellaria]
Eleocharis sp.			X	Pfaf (2016) [Eleocharis]
Scirpus sp.				No information available
Avena sp.	X			ECOCROP (2016) [Avena] – well drained
Polygonaceae			X	Various
Cyperaceae			X	Various
Fabaceae			X	Various
Rumex sp.		(X)		Tropicos (2016) [Rumex] statement that can produce rhizomes and vegetation spread but no statement on seed dormancy

Table S2.xi. Details by species for root system of weeds

	Tap root	Rhizome	Both	References
Chenopodium album	X			Weedecology (2016) [Chenopodium]
Fumaria sp.	X			Gupta & Rao (2012); Murrumbidgee (2016) [Fumitory_revised]
Trianthema triquetra/ portulacastrum	X			Botanicgardens (2016) [Trianthema]
Solanum dulcamara				No information available
Coix lacrym-jobi				No information available
Chrysopogon cf. *aciculatus*		X		ECOCROP (2016) [Chrysopogon]
Echinochloa crus-galli		X		Galinato et al. (1999); ECOCROP (2016) [Echinochloa]
Papaver cf. *rhoeas*	X			McNaughton & Harper (1964); ECOFLORA (2016) [Papaver]
Pennisetum glaucum		X		FAO (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used		X		ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used		X		Idao (2016) [Brachiaria]; Icunredlist (2016) [Brachiaria]; ECOCROP (2016) [Brachiaria]
Wild *Hordeum* (*murinum*)			X	Not a deep tap root but not rhizomous in its spread Archive (2016) [Hordeum]
Aeluropus sp. *lagopoides* used		X		Tropicos (2016) [Aeluropus]; Kew (2016) [Aeluropus]
Eragrostis sp.			X	Not a deep tap root but not rhizomous in its spread ECOCROP (2016) [Eragrostis]
Medicago/Melilotus/Trifolium	X			Fed (2016) [Melilotus]; Ucanr (2016) [Medicago]; Ibaf (2016) [Medicago]
Stellaria sp.			X	Shallow tap root with rhizomes Ucipm (2016) [Stellaria];

			Pfaf (2016) [Stellaria];
Eleocharis sp.	X		Matting Tropicos (2016) [Eleocharis]
Scirpus sp.			No information available
Avena sp.		X	Not a deep tap root but not rhizomous in its spread ECOCROP (2016) [Avena]
Polygonaceae		X	Unknown species so assume both types possible
Cyperaceae		X	Unknown species so assume both types possible
Fabaceae		X	Unknown species so assume both types possible
Rumex sp.		X	Can produce rhizomes along tap root Tropicos (2016) [Rumex]

Table S2.xii. Details by species for soil depth of weeds

	Shallow	Deep	References
Chenopodium album		X	Weedecology (2016) [Chenopodium]
Fumaria sp.	X		Gupta & Rao (2012)
Trianthema triquetra/ portulacastrum		X	Hooker (1875)
Solanum dulcamara			No information available
Coix lacrym-jobi			No information available
Chrysopogon cf. *aciculatus*	X		ECOCROP (2016) [Chrysopogon]
Echinochloa crus-galli	X		Galinato et al. (1999); ECOCROP (2016) [Echinochloa]
Papaver cf. *rhoeas*	X		ECOFLORA (2016) [Fumaria]
Pennisetum glaucum		X	Deep soil needed Galinato et al. (1999); FAO (2016) [Pennisetum]; ECOCROP (2016) [Pennisetum]; CAES (2016) [Pennisetum]
Paspalum sp. – *scrobiculatum* used		X	ECOCROP (2016) [Paspalum]
Brachiaria sp. *ramosa* used	X		ECOCROP (2016) [Brachiaria]
Wild *Hordeum* (*murinum*)	X		Archive (2016) [Hordeum]
Aeluropus sp. *lagopoides* used	X		Tropicos (2016) [Aeluropus]
Eragrostis sp.	X		ECOCROP (2016) [Eragrostis]
Medicago/Melilotus/Trifolium	X		Fed (2016) [Melilotus]; Ucanr (2016) [Medicago]
Stellaria sp.	X		Ucipm (2016) [Stellaria]; Illinoiswildflowers (2016) [Stellaria]; PSU (2016) [Stellaria]
Eleocharis sp.	X		Tropicos (2016) [Eleocharis]
Scirpus sp.			No information available
Avena sp.	X		ECOCROP (2016) [Avena]
Polygonaceae			No information available
Cyperaceae			No information available
Fabaceae			No information available
Rumex sp.	X		Tropicos (2016) [Rumex]

SI.2. Crop and weed species identified at Land, Water and Settlement *sites*

Table S3. Presence/absence of crop species by site (after Bates 2016: Table 7.1)

Species	Species Code	DVC (MH)	Burj (EH)	Burj (PGW)	MSD VII (EH)	MSD VII (MH)	MSD VII (LH)	MSD I (MH)	BHA (LH)	BHA (PGW)
Hordeum vulgare	Hord.	X	X	X	X	X	X	X	X	X
Triticum sp.	Trit.	X		X	X	X		X		X
Triticum cf. *durum/aestivum*				X	X	X		X		
Hordeum/Triticum	H/T	X	X	X	X	X	X	X	X	X
Oryza sp.	Oryza				X		X	X	X	X
Echinochloa sp.	Ech.			X	X	X	X	X	X	X
Echinochloa colona				X	X	X		X	X	X
Setaria sp.	Set.	X		X	X			X	X	X
Setaria cf. *pumila*				X	X			X	X	X
Panicum sp.	Pan.	X		X	X		X	X	X	X
SEB[2]	SEB	X		X	X	X		X	X	X
Indeterminate small millet	Indet. M.	X		X	X	X	X	X	X	X
Vigna sp.	Vig.			X	X	X	X	X	X	X
Vigna radiata	Vig. rad.			X		X		X	X	X
Vigna mungo	Vig. mun.						X	X	X	
Vigna radiata/mungo	Vig. r/m				X	X		X	X	
Vigna acconitifolia	Vig. acc.						X	X		
Vigna cf. *trilobata*	Vig. tri.							X	X	
Macrotyloma cf. *uniflorum*	Mac.				X	X	X	X	X	X
Pisum sp.	Pis.			X	X		X	X		
Cicer arientinum	Cic.			X	X		X	X		
Lens cf. *culinaris*	Lens	X						X		X
Lathyrus sp.	Lath.			X				X		
Vicia/Lathyrus	Vic/Lath				X	X		X		
Indeterminate Fabaceae	Indet. Fab.	X		X	X	X	X	X	X	X
Ziziphus mauritiana	Zizi.	X	X	X	X	X	X	X	X	X

[2] SEB – *Setaria/Echinochloa/Brachiaria*: a complex of small millets with long embryos which can be difficult to distinguish between if the grain is damaged (after Fuller, 2000).

Indeterminate Fruit	Indet. Fruit	X	X	X	X	X	X	X	X	X
Brassica sp.	Bras.	X			X	X		X		X
cf. *Indigofera* sp.	Indig.							X		X
Coccinia cf. *grandis*	Coc. gr.				X		X	X	X	X
Sesamum indicum	Ses.							X		
Linum cf. *usitatissimum*	Linum							X		
Indeterminate Oilseed/ Fibre	Indet O/F				X			X		X

Table S4. Presence/absence of weed species by site (after Bates 2016: Table 7.2)

Species	Species Code	DVC (MH)	Burj (EH)	Burj (PGW)	MSD VII (EH)	MSD VII (MH)	MSD VII (LH)	MSD I (MH)	BHA (LH)	BHA (PGW)
Trianthema triquetra	Tri.	X			X			X	X	
Stellaria sp.	Stell.	X		X	X	X	X	X	X	X
Stellaria cf. *nemorum*	Stell. Nem.							X		
Chenopodium sp.	Cheno.	X						X	X	X
Eleocharis sp.	Eleo.	X			X	X	X	X	X	X
Cf. *Scirpus* sp.	Scirpus			X	X	X	X	X		X
Cyperaceae	Cyp.	X		X	X	X	X	X	X	X
Acacia sp.	Aca.							X		
Medicago/Melilotus/Trifolium	MMT							X		
Small round Fabaceae	Round Fab.	X		X	X			X	X	X
Small reniform Fabaceae	Reni. Fab.				X			X	X	
Small Fabacaeae	Fab.			X	X		X	X	X	X
Mimosoideae	Mim.							X		
Fumaria cf. *officinalis*	Fum.			X	X			X		
Papaveraceae	Pap.						X			
Aelupurus sp.	Ael.							X		
cf. *Avena* sp.	Avena	X						X		
Brachiaria sp.	Brach.							X		
cf. *Chrysopogon* sp.	Chrys.	X		X	X	X		X	X	X
Coix lacryma-jobi	Coix							X		
Echinochloa crus-galli	Ech. c-g			X				X	X	

Eragrostis sp.	Erag.	X						X		X
cf. *Paspalum* sp.	Pasp.									X
cf. *Pennisetum* sp.	Penn.			X			X			
Indet. Big Millet	Big M.						X	X		
Large grass	Large Grass							X		
Indet. Grass Type 1	Grass 1	X			X			X	X	X
Indeterminate Small Grass	Indet. Grass	X	X	X	X	X	X	X	X	X
Rumex cf. *crispus*	Rum.								X	
Polygonaceae	Poly.	X			X			X		X
Solanum cf. *dulcamara*	Sol.				X			X		
Indet curled embryo	Curled	X						X	X	
Indet. small round seed	Round	X		X	X	X	X	X	X	X

SI.3. Dabli-vas Chugta

Table S5. Proportion of crop genera of crop assemblage at Dabli vas Chugta (after Bates 2016: Table 9.1)

Crop Taxa	Proportion of assemblage	Season
Hordeum vulgare	34.26%	W
Triticum sp.	0.78%	W
Hordeum/Triticum	15.70%	W
Setaria sp.	0.78%	S
Panicum sp.	0.78%	S
SEB	3.89%	S
Indet. small millet	19.47%	S
Lens cf. *culinaris*	2.91%	W
Indet. Fabaceae	11.52%	W/S/P
Ziziphus mauritiana	2.88%	P
Indet. Fruit	1.73%	P
Brassica sp.	5.31%	W
Summer crops	24.91%	
Winter crops	58.95%	
Tree/orchard	4.61%	
Unknown	11.25%	

Table S6. Average count per 10l sediment of weed genera at Dabli vas Chugta (after Bates 2016: Table 7.4)

Weed Taxa	Count per 10l	Season
Stellaria sp.	0.01	S
Eleocharis	0.25	S
Trianthema triquetra	0.15	S
Eragrostis sp.	0.01	S
Chrysopogon sp.	0.08	S
Avena sp.	0.03	W
Chenopodium album	0.01	W/S
Cyperaceae	0.01	W/S/P
Indeterminate grass	0.39	W/S/P
Small round Fabaceae	0.03	W/S/P
Indet. curled embryo	0.08	W/S/P
Round	0.87	W/S/P
Indet. seed	0.14	W/S/P
Summer weeds	92.59%	
Winter weeds	5.56%	
Both seasons weeds	1.85%	

Table S7: Relative proportions of summer weeds at Dabli vas Chugta by ecological preference indicators (after Bates 2016: Table 10.1)

Water	*Wet* 77.99%	*Moist* 20.30%	*Dry* 1.96%	
Flood Tolerance	*Flood* 48.58%	*Drought* 17.65%	*Neither* 34.02%	
Soil Depth	*Shallow* 68.87%	*Deep* 31.37%		
Root Type	*Rhizomes* 66.23%	*Tap* 31.37%	*Both* 2.65%	
Soil Texture	*Sand* 45%	*Loam* 0%	*Clay* 0%	*Any* 55%
Soil Fertility	*Fertile* 1.96%	*Between* 98.29%	*Infertile* 0%	
Soil pH	*Acid* 17.65%	*Alkali* 32.06%	*Neutral* 48.58%	*Any* 1.96%
Reproduction	*Seed bank* 33.33%	*Vegetal Spread* 15.69%	*Both* 51.23%	
Reproductive Cycle	*Annual* 33.33%	*Biannual* 51.23%	*Perennial* 15.69%	

SI.4. Burj

Table S8. Proportion of crop genera of crop assemblage at Burj in the Early Harappan period (after Bates 2016: Table 9.3)

Crop Genera	Proportion of Assemblage	Season
Hordeum vulgare	8.33%	W
Hordeum/Triticum	33.33%	W
Ziziphus mauritiana	16.67%	P
Indet. fruit	41.67%	P
Summer crops	0%	
Winter crops	41.66%	
Tree/Orchard	58.34%	
Unknown	0%	

Table S9. Proportion of crop genera of crop assemblage at Burj in the PGW period (after Bates 2016: Table 7.6)

Crop Genera	Proportion of Assemblage	Season
Hordeum vulgare	5.42%	W
Triticum sp.	0.24%	W
Hordeum/Triticum	3.30%	W
Echinochloa sp.	42.69%	S
Setaria sp.	23.11%	S
Panicum sp.	3.07%	S
SEB	5.66%	S
Indet. small millet	6.84%	S
Vigna sp.	1.65%	S
Vigna radiata	0.24%	S
Pisum sp.	0.47%	W
Cicer arientinum	0.24%	W
Lathyrus sp.	0.24%	W
Indet. Fabaceae	0.94%	W/S/P
Ziziphus mauritiana	2.59%	P
Indet. fruit	3.30%	P
Summer crops	83.25%	
Winter crops	9.91%	
Tree/Orchard	5.90%	
Unknown	0.94%	

Table S10. Average count per 10l sediment of weed genera at Burj in the PGW period (after Bates 2016: Table 7.6)

Weed Taxa	Count per 10l	Season
Stellaria sp.	0.57	S
Fumaria cf. *officinalis*	0.04	S
Chrysopogon sp.	0.04	S
Echinochloa crus-galli	0.07	S
Pennisetum sp.	0.07	S
Cyperaceae	0.38	W/S/P
Fabaceae	0.11	W/S/P
Indeterminate small grass	0.32	W/S/P
Round	0.18	W/S/P
Indet. seed	.04	W/S/P
Summer weeds	100%	
Winter weeds	0%	
Both seasons weeds	0%	

Table S11. Relative proportion of summer weeds at Burj in the PGW period by ecological preference indicators (after Bates 2016: Table 10.2)

Water	*Wet* 0%	*Moist* 90.91%	*Dry* 9.09%	
Flood Tolerance	*Flood* 9.09%	*Drought* 18.08%	*Neither* 72.33%	
Soil Depth	*Shallow* 90.91%	*Deep* 9.09%		
Root Type	*Rhizomes* 22.73%	*Tap* 4.55%	*Both* 72.73%	
Soil Texture	*Sand* 22.73%	*Loam* 0%	*Clay* 0%	*Any* 76.85%
Soil Fertility	*Fertile* 9.09%	*Between* 86.36%	*Infertile* 4.55%	
Soil pH	*Acid* 13.64%	*Alkali* 77.27%	*Neutral* 9.09%	*Any* 0%
Reproduction	*Seed bank* 4.55%	*Vegetal Spread* 4.52	*Both* 90.42%	
Reproductive Cycle	*Annual* 22.73%	*Biannual* 72.73%	*Perennial* 4.55%	

SI.5. Masudpur VII

Table S12. Proportions of crop genera of crop assemblage at Masudpur VII (after Bates 2016: Table 9.5). It should be noted that there were only three samples from the Late Harappan period, and that low sample number bias may have affected results.

Crop Genera	Proportion of Assemblage *Early Harappan*	*Mature Harappan*	*Late Harappan*	Season
Hordeum vulgare	15.82%	1.59%	0.86%	W
Triticum sp.	1.27%	19.05%		W
Hordeum/Triticum	4.43%	28.57%	7.76%	W
Oryza sp.	1.27%		6.03%	S
Echinochloa sp.	18.35%	12.60%	6.03%	S
Setaria sp.	6.96%			S
Panicum sp.	4.43%		0.86%	S
SEB	5.06%	3.17%		S
Indet. small millet	7.60%	4.76%	10.34%	S
Vigna sp.	0.63%	3.17%	4.31%	S
Vigna radiata		3.17%		S
Vigna mungo			1.72%	S
Vigna radiata/mungo	0.63%	1.59%		S
Vigna acconitifolia			0.86%	S
Macrotyloma cf. *uniflorum*	13.29%	3.17%	5.17%	S
Pisum sp.	0.63%		0.86%	W
Cicer arientinum	1.27%		1.72%	W
Vicia/Lathyrus	1.27%	1.59%		W
Indet. Fabaceae	4.43%	3.17%	5.17%	W/S/P
Ziziphus mauritiana	5.70%	6.35%	2.59%	P
Indet. Fruit	1.89%	6.35%	0.86%	P
Brassica sp.		1.659%		W
Coccinia cf. *grandis*	0.63%		44.81%	S
Indet. Oilseed/Fibre	4.43%			W/S/P
Summer crops	58.87%	31.75%	80.17%	
Winter crops	24.68%	52.38%	11.20%	
Tree/Orchard	7.59%	12.70%	3.45%	
Unknown	8.86%	3.17%	5.17%	

Table S13. Average count per 10l sediment of weed genera at Masudpur VII in the Early Harappan period (after Bates 2016: Table 7.8)

Weed Taxa	Count per 10l	Season
Stellaria sp.	4.6	S
Eleocharis sp.	1.15	S
Fumaria cf. *officinalis*	0.2	S
Trianthema triquetra	0.15	S

Chrysopogon sp.	0.05	S
Polygonaceae	0.1	W/S/P
Cyperaceae	5.95	W/S/P
Fabaceae	0.45	W/S/P
Indeterminate small grass	1.05	W/S/P
Solanum dulcamara	0.1	Tree
Round	0.9	W/S/P
Indet. seed	1.65	W/S/P
Summer weeds	100%	
Winter weeds	0%	
Both seasons weeds	0%	

Table S14. Relative proportion of summer weeds at Masudpur VII in the Early Harappan period by ecological preference indicators (after Bates 2016: Table 10.3)

Water	*Wet* 21.14%		*Moist* 78.86%	*Dry* 0%
Flood Tolerance	*Flood* 18.70%		*Drought* 4.07%	*Neither* 77.24%
Soil Depth	*Shallow* 97.56%		*Deep* 2.44%	
Root Type	*Rhizomes* 19.51%		*Tap* 5.69%	*Both* 74.80%
Soil Texture	*Sand* 3.25%	*Loam* 0%	*Clay* 0%	*Any* 96.75%
Soil Fertility	*Fertile* 0%		*Between* 96.75%	*Infertile* 3.25%
Soil pH	*Acid* 0.81%	*Alkali* 80.49%	*Neutral* 18.70%	*Any* 0%
Reproduction	*Seed bank* 5.69%		*Vegetal Spread* 0.81%	*Both* 93.50%
Reproductive Cycle	*Annual* 5.69%		*Biannual* 93.50%	*Perennial* 0.81%

Table S15. Average count per 10l sediment of weed genera at Masudpur VII in the Mature Harappan (after Bates 2016: Table 7.8)

Weed Taxa	Count per 10l	Season
Stellaria sp.	0.21	S
Eleocharis sp.	0.13	S
Chrysopogon sp.	0.04	S
Cyperaceae	1.75	W/S/P
Indeterminate small grass	0.21	W/S/P

Round	0.63	W/S/P
Indet. seed	0.13	W/S/P
Summer weeds	100%	
Winter weeds	0%	
Both seasons weeds	0%	

Table S16. Percentages of summer weeds from the Mature Harappan period at Masudpur VII by ecological preference indicators (after Bates 2016: Table 10.4)

Water	*Wet* 33.33%	*Moist* 66.67%		*Dry* 0%
Flood Tolerance	*Flood* 33.33%	*Drought* 11.11%		*Neither* 88.89%
Soil Depth	*Shallow* 100%		*Deep* 0%	
Root Type	*Rhizomes* 44.44%	*Tap* 0%		*Both* 55.56%
Soil Texture	*Sand* 11.11%	*Loam* 0%	*Clay* 0%	*Any* 88.89%
Soil Fertility	*Fertile* 0%	*Between* 100%		*Infertile* 0%
Soil pH	*Acid* 11.11%	*Alkali* 55.56%	*Neutral* 33.33%	*Any* 0%
Reproduction	*Seed bank* 0%	*Vegetal Spread* 11.11%		*Both* 88.89%
Reproductive Cycle	*Annual* 0%	*Biannual* 88.89%		*Perennial* 11.11%

Table S17. Average count per 10l sediment of weed genera at Masudpur VII in the Late Harappan (after Bates 2016: Table 7.8). It should be noted that there were only three samples, and that low sample number bias may have affected results.

Weed Taxa	Count per 10l	Season
Stellaria sp.	1.5	S
Eleocharis sp.	0.33	S
cf. *Papaver rhoeas*	0.17	S
Pennisetum sp.	0.17	S
Chrysopogon sp.	0.05	S
Indet. Big Millet	0.17	S
Cyperaceae	3.5	W/S/P
Fabaceae	0.5	W/S/P
Indeterminate small grass	0.33	W/S/P
Round	3.33	W/S/P

Indet. seed	0.5	W/S/P
Summer weeds	100%	
Winter weeds	0%	
Both seasons weeds	0%	

Table S18. Relative proportion of summer weeds in the Late Harappan at Masudpur VII by ecological preference indicators (after Bates 2016: Table 10.5). It should be noted that there were only three samples, and that low sample number bias may have affected results.

Water	*Wet* 15.38%	*Moist* 76.92%	*Dry* 7.69%	
Flood Tolerance	*Flood* 15.38%	*Drought* 7.69%	*Neither* 76.92%	
Soil Depth	*Shallow* 92.31%	*Deep* 7.69%		
Root Type	*Rhizomes* 23.08%	*Tap* 7.69%	*Both* 69.23%	
Soil Texture	*Sand* 15.38%	*Loam* 0%	*Clay* 0%	*Any* 84.62%
Soil Fertility	*Fertile* 7.69%	*Between* 92.31%	*Infertile* 0%	
Soil pH	*Acid* 7.69%	*Alkali* 69.23%	*Neutral* 15.38%	*Any* 7.69%
Reproduction	*Seed bank* 7.69%	*Vegetal Spread* 0%	*Both* 92.31%	
Reproductive Cycle	*Annual* 15.38%	*Biannual* 84.62%	*Perennial* 0%	

SI.6. Masupdur I

Table S19. Proportion of crop genera of crop assemblage at Masudpur I (after Bates 2016: Table 9.7)

Crop Genera	Proportion of Assemblage	Season
Hordeum vulgare	17.75%	W
Triticum sp.	1.65%	W
Hordeum/Triticum	8.59%	W
Oryza sp.	19.34%	S
Echinochloa sp.	11.55%	S
Setaria sp.	15.48%	S
Panicum sp.	3.49%	S
SEB	3.62%	S
Indet. small millet	7.77%	S
Vigna sp.	1.43%	S

Vigna radiata	0.58%	S
Vigna mungo	0.13%	S
Vigna radiata/mungo	0.02%	S
Vigna acconitifolia	0.30%	S
Vigna trilobata	0.16%	S
Macrotyloma cf. *uniflorum*	1.36%	S
Pisum sp.	0.10%	W
Cicer arientinum	0.26%	W
Lens cf. *culinaris*	0.14%	W
Lathyrus sp.	0.06%	W
Vicia/Lathyrus	0.04%	W
Indet. Fabaceae	1.21%	W/S/P
Ziziphus mauritiana	0.51%	P
Indet. fruit	0.09%	P
Brassica sp.	0.09%	W
Sesamum indicum	0.48%	S
Coccinia cf. *grandis*	0.34%	S
Indigofera sp.	0.07%	S
Linum sp.	0.19%	W
Indet. Oilseed/Fibre	3.18%	W/S/P
Summer crops	66.12%	
Winter crops	28.87%	
Tree/Orchard	0.60%	
Unknown	4.39%	

Table S20. Average count per 10l of sediment of weed genera at Masudpur I (after Bates 2016: Table 7.10)

Weed Taxa	Proportion of assemblage	Season
Stellaria sp.	0.06	S
Eleocharis sp.	0.34	S
Fumaria cf. *officinalis*	0.16	S
Trianthema triquetra	0.27	S
Eragrostis sp.	7.83	S
Aeluropus sp.	0.14	S
Chrysopogon sp.	0.73	S
Brachiaria sp.	0.05	S
Indet. big millet	0.03	S
Medicago/Melilotus/Trifolium	0.99	W
Avena sp.	0.07	W
Chenopodium album	0.05	W/S
Solanum cf. *dulcamara*	0.06	(Tree/shrub)

Mimosoideae	0.16	(Tree)
Acacia sp.	0.12	(Tree)
Cyperaceae	4.82	W/S/P
Polygonaceae	0.07	W/S/P
Fabaceae	0.06	W/S/P
Indet. small grass	2.85	W/S/P
Small cereal	1.49	W/S/P
Round	122.98	W/S/P
Indet. curled embryo	0.31	W/S/P
Indet. seed	4.35	W/S/P
Summer weeds	89.72%	
Winter weeds	9.44%%	
Both seasons weeds	0.46%	

Table S21. Relative proportion of winter weeds at Masupdur I by ecological preference indicators (after Bates 2016: Table 10.6)

Water	*Wet* 0%		*Moist* 93.78%	*Dry* 6.22%
Flood Tolerance	*Flood* 0%		*Drought* 93.78%	*Neither* 6.22%
Soil Depth	*Shallow* 6.22%		*Deep* 4.67%	*Unknown* 89.11%
Root Type	*Rhizomes* 6.22%		*Tap* 93.60%	*Both* 0%
Soil Texture	*Sand* 0%	*Loam* 0%	*Clay* 0%	*Any* 100%
Soil Fertility	*Fertile* 4.67%		*Between* 95.33%	*Infertile* 0%
Soil pH	*Acid* 6.22%	*Alkali* 89.11%	*Neutral* 0%	*Any* 4.67%
Reproduction	*Seed bank* 100%		*Vegetal Spread* 0%	*Both* 0%
Reproductive Cycle	*Annual* 4.67%		*Biannual* 95.33%	*Perennial* 0%

Table S22. Relative proportion of summer weeds at Masupdur I by ecological preference indicators (after Bates 2016: Table 10.7)

Water	*Wet* 6.40%	*Moist* 12.93%	*Dry* 80.67%
Flood Tolerance	*Flood*	*Drought*	*Neither*

	4.22%	11.74%	84.04%	
Soil Depth	*Shallow* 96.54%	*Deep* 3.46%		
Root Type	*Rhizomes* 94.23%	*Tap* 5.15%	*Both* 0.62%	
Soil Texture	*Sand* 12.85%	*Loam* 0%	*Clay* 0%	*Any* 87.15%
Soil Fertility	*Fertile* 1.29%	*Between* 97.02%	*Infertile* 1.69%	
Soil pH	*Acid* 7.72%	*Alkali* 87.15%	*Neutral* 4.60%	*Any* 0.53%
Reproduction	*Seed bank* 85.63%	*Vegetal Spread* 9.15%	*Both* 5.21%	
Reproductive Cycle	*Annual* 86.77%	*Biannual* 4.26%	*Perennial* 8.97%	

SI.7. Bahola

Table S23. Proportion of crop genera of crop assemblage at Bahola in the Late Harappan and PGW periods (after Bates 2016: Table 9.9)

Crop Genera	Proportion of Assemblage		Season
	Late Harappan	*PGW*	
Hordeum vulgare	0.68%	2.47%	W
Triticum sp.		1.28%	W
Hordeum/Triticum	6.20%	10.71%	W
Oryza sp.	17.35%	9.10%	S
Echinochloa sp.	25.82%	16.27%	S
Setaria sp.	14.83%	9.33%	S
Panicum sp.	0.68%	4.68%	S
SEB	1.88%	4.37%	S
Indet. small millet	17.20%	25.18%	S
Vigna sp.	4.99%	0.77%	S
Vigna radiata	0.92%	1.55%	S
Vigna mungo	0.22%		S
Vigna radiata/mungo	0.11%		S
Vigna trilobata	0.33%		S
Macrotyloma cf. *uniflorum*	3.66%	0.77%	S
Lens cf. *culinaris*		1.55%	W
Indet. Fabaceae	4.43%	4.17%	W/S/P
Ziziphus mauritiana	0.33%	4.81%	P
Indeterminate Fruit	0.13%		P
Brassica sp.		1.28%	W
Coccinia cf. *grandis*	0.22%		S
Indigofera sp.		0.85%	S

Indet. Oilseed/Fibre		0.85%	W/S/P
Summer crops	88.24%	72.88%%	
Winter crops	6.87%	17.29%	
Tree/Orchard	0.46%	4.81%	
Unknown	4.43%	5.02%	

Table S24. Average count per 10l of sediment of weed genera at Bahola in the Late Harappan (after Bates 2016: Table 7.12)

Weed Taxa	Count per 10l	Season
Stellaria sp.	0.02	S
Eleocharis sp.	1.13	S
Eragrostis sp.	0.20	S
Chrysopogon sp.	5.16	S
Echinochloa crus-galli	0.02	S
Rumex sp.	0.02	W
Cheopodium album	1.58	W/S
Cyperaceae	11.15	W/S/P
Fabaceae	0.62	W/S/P
Indet. small grass	2.16	W/S/P
Indet. curled embryo	0.02	W/S/P
Round	0.92	W/S/P
Indet. seed	2.48	W/S/P
Summer weeds	80.39%	
Winter weeds	0.25%	
Both seasons weeds	19.36%	

Table S25. Relative proportion of winter weeds at Late Harappan period Bahola by ecological preference indicators (after Bates 2016: Table 10.8)

Water	*Wet* 1.05%	*Moist* 98.95%	*Dry* 0%	
Flood Tolerance	*Flood* 0%	*Drought* 98.95%	*Neither* 1.05%	
Soil Depth	*Shallow* 0%	*Deep* 100%		
Root Type	*Rhizomes* 0%	*Tap* 100%	*Both* 0%	
Soil Texture	*Sand* 0%	*Loam* 0%	*Clay* 1.05%	*Any* 98.95%
Soil Fertility	*Fertile* 98.95%	*Between* 1.05%	*Infertile* 0%	

Soil pH	*Acid* 98.95%	*Alkali* 0%	*Neutral* 1.05%	*Any* 0%
Reproduction	*Seed bank* 98.95%	*Vegetal Spread* 1.05%	*Both* 0%	
Reproductive Cycle	*Annual* 98.95%	*Biannual* 0%	*Perennial* 1.05%	

Table S26. Relative proportion of summer weeds in the Late Harappan at Bahola by ecological preference indicators (after Bates 2016: Table 10.9)

Water	*Wet* 14.31%	*Moist* 83.18%	*Dry* 2.51%	
Flood Tolerance	*Flood* 14.14%	*Drought* 82.73%	*Neither* 3.13%	
Soil Depth	*Shallow* 80.23%	*Deep* 19.77%		
Root Type	*Rhizomes* 80.02%	*Tap* 19.77%	*Both* 0.21%	
Soil Texture	*Sand* 64.01%	*Loam* 0%	*Clay* 0%	*Any* 35.99%
Soil Fertility	*Fertile* 19.60%	*Between* 80.40%	*Infertile* 0%	
Soil pH	*Acid* 63.37%	*Alkali* 3.13%	*Neutral* 14.14%	*Any* 19.36%
Reproduction	*Seed bank* 22.28%	*Vegetal Spread* 63.37%	*Both* 14.35%	
Reproductive Cycle	*Annual* 22.52%	*Biannual* 14.12%	*Perennial* 63.37%	

Table S27. Average count per 10l of sediment of weed genera at Bahola in the PGW period (after Bates 2016: Table 7.12)

Weed Taxa	Count per 10l	Season
Stellaria sp.	0.07	S
Eleocharis sp.	0.18	S
Eragrostis sp.	0.31	S
Chrysopogon sp.	0.06	S
Paspalum sp.	0.03	S
Cheopodium album	0.03	W/S
Cyperaceae	1.78	W/S/P
Polygonaceae	0.03	W/S/P
Fabaceae	0.15	W/S/P
Indet. small grass	0.75	W/S/P
Round	0.07	W/S/P

Indet. seed	0.98	W/S/P
Summer weeds	95.59%	
Winter weeds	0%	
Both seasons weeds	4.41%	

Table S28. Relative proportion of summer weeds at PGW period Bahola by ecological preference indicators (after Bates 2016: Table 10.10)

Water	*Wet* 30.35%	*Moist* 23.74%	*Dry* 45.91%	
Flood Tolerance	*Flood* 30.35%	*Drought* 13.89%	*Neither* 55.77%	
Soil Depth	*Shallow* 95.07%	*Deep* 4.93%		
Root Type	*Rhizomes* 85.22%	*Tap* 4.93%	*Both* 9.85%	
Soil Texture	*Sand* 8.96%	*Loam* 0%	*Clay* 0%	*Any* 91.04%
Soil Fertility	*Fertile* 8.62%	*Between* 91.31%	*Infertile* 0%	
Soil pH	*Acid* 12.65%	*Alkali* 55.77%	*Neutral* 26.65%	*Any* 4.93%
Reproduction	*Seed bank* 50.84%	*Vegetal Spread* 12.65%	*Both* 36.51%	
Reproductive Cycle	*Annual* 50.84%	*Biannual* 40.20%	*Perennial* 8.96%	

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